Water Circulation and Management of Infectious Salmon Anemia in the Salmon Aquaculture Industry in Passamaquoddy Bay, Southwestern New Brunswick

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ABSTRACT

Chang, B.D., Page, F.H., Losier, R.J., Greenberg, D.A., Chaffey, J.D., and McCurdy, E.P. 2006. Water circulation and management of infectious salmon anemia in the salmon aquaculture industry of Passamaquoddy Bay, southwestern New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 2622: iii + 46 p.

Infectious salmon anemia (ISA) was first detected in salmon farms in southwestern New Brunswick in 1996. In an effort to help estimate the potential for water-borne exchange of the ISA virus among farms in this area, we used a three-dimensional tidal water circulation and particle transport model. Water exchange scenarios based on the movement of particles during one tidal excursion, as predicted by the model, are compared to those estimated by a simple method assuming a 5-km radius circular zone of water exchange around each farm. In this report, we examined the water exchange among farms in the Passamaquoddy Bay area, as well as with farms in adjacent areas. We also examined the relative risks, with respect to the water-borne spread of disease, of two potential locations for a proposed new salmon farm in northern Passamaquoddy Bay.

RÉSUMÉ

Chang, B.D., Page, F.H., Losier, R.J., Greenberg, D.A., Chaffey, J.D., and McCurdy, E.P. 2006. Water circulation and management of infectious salmon anemia in the salmon aquaculture industry in Passamaquoddy Bay, southwestern New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 2622: iii + 46 p.

Au Canada, l'anémie infectieuse du saumon (AIS) a été décelée pour la première fois dans des salmonicultures du sud-ouest du Nouveau-Brunswick en 1996. Nous avons utilisé un modèle tridimensionnel de circulation des eaux de marée et un modèle de transport des particules pour estimer le potentiel de transmission hydrique du virus de l'AIS entre les fermes de la région. Puis nous avons comparé des scénarios d'échange d'eau reposant sur la circulation des particules durant une marée, telle que prédite par le modèle, et des scénarios estimés à l'aide d'une méthode simple qui supposent que l'échange d'eau autour de chaque ferme se produit dans un rayon de 5 km. Nous examinons ici l'échange d'eau entre les fermes établies dans la baie Passamaquoddy, ainsi qu'entre ces fermes et des fermes établies dans les eaux voisines. Nous évaluons aussi les risques relatifs de propagation hydrique des maladies des poissons que posent deux emplacements potentiels où l'on prévoit établir une nouvelle salmoniculture dans le nord de la baie Passamaquoddy.

INTRODUCTION

BACKGROUND

Infectious salmon anemia (ISA) first appeared among salmon farms in southwestern New Brunswick (SWNB) in the summer of 1996 and has been present every year since, resulting in considerable economic loss (McGeachy and Moore 2003). As part of the management strategy for this disease, the salmon farming region of SWNB was partitioned into Bay Management Areas (BMAs) (New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA) 2000). The intent of BMAs is to improve cooperation and communication among farm operators, in order to assist in fish health and environmental management. All farms within the same BMA are encouraged to synchronize the placement and harvesting of fish. The boundaries of the BMAs (Fig. 1) were based on fish health, economic and oceanographic considerations (Halse 2002). Initially, oceanographic considerations were a relatively minor factor in defining BMAs, due in part to a lack of oceanographic knowledge.

Farms in Passamaquoddy Bay (BMAs 1a, 1b, 2, 3, and parts of 4 and 7) were first infected with ISA in late 1998 (NBDAFA, pers. comm.). Following the initial outbreaks, farms in the northern part of Passamaquoddy Bay (BMA 1a) were synchronized as odd year-class farms (smolt entry in the spring of odd years), while farms in the southern part of Passamaquoddy Bay (BMAs 1b, 2, 3, 4, and the northern part of 7) were synchronized as even year-class farms. Despite fallowing and synchronization of smolt entry in these areas, subsequent year-classes have become infected with ISA.

The main objectives of this project were to examine the potential for the water-borne spread of ISA virus among farms in Passamaquoddy Bay, as well as with farms in adjacent areas, and the validity of the existing BMA boundaries in this area. We examined these issues using a three-dimensional tidal circulation and particle transport model. The model results were compared to a simpler approach using a circular zone of influence around each farm. The methodology used in this study was originally developed to examine fish health and oceanography issues at salmon farms in the southern Grand Manan Island area of SWNB (Page and Chang 2002; Page et al. 2004, 2005). This approach has subsequently been applied to other salmon farming areas in SWNB: Letete Passage, Back Bay, Bliss Harbour, and Lime Kiln Bay (Chang et al. 2005b); southern Deer Island, Campobello Island, and adjacent Cobscook Bay, Maine (Chang et al. 2005a); and the eastern Grand Manan Island area (Chang et al. 2006). In this report, we also examined the relative risks, with respect to the water-borne spread of ISA virus, of two locations for a proposed new salmon farm in northern Passamaquoddy Bay.

CAUSES OF THE SPREAD OF ISA AMONG SALMON FARMS

Previous studies have suggested that, at the larger scale (in the order of tens of kilometres or more), the spread of ISA is likely related to vectors such as boat traffic and the transport of fish among farms. However, at the smaller tidal excursion scale, physical transport of the ISA virus (from infected fish and discharged fish wastes) in the sea is a possible mechanism for disease spread (Murray et al. 2002). Such passive transport would be in the order of a few kilometres or less, limited by the tidal exchange around farms (JGIWG 2000; Murray 2003). The pattern of

occurrence of ISA in SWNB (McGeachy and Moore 2003; McClure et al. 2004) suggests that both large scale vectors (such as movement of boats, fish, personnel, and equipment among farms), and smaller scale passive transport in seawater among adjacent farms have occurred.

FISH HEALTH MANAGEMENT ZONES IN OTHER SALMON FARMING AREAS

Hydrographically defined control and surveillance zones or management areas have been implemented in other salmon farming areas as a way to reduce the spread of ISA among salmon farms (Stewart 1998). The Norwegian Animal Health Authority's (2002) "Contingency plan for the control of infectious salmon anaemia in Norway" includes the establishment of Control Zones around ISA-infected farms. The Control Zone is a circular area with a radius of at least one tidal excursion (where known), but not less than 5 km, centred on the infected farm. Conditions applied to all farms within the Control Zone include: increased fish health surveillance; a prohibition of fish movement into or out of the zone; restrictions on the transport of fish through the zone; and a requirement for fallowing and disinfection of all farms prior to restocking. In addition, there is a larger Surveillance Zone which includes all farms whose Control Zones overlap with the Control Zone of the infected farm (a 10- to 20-km radius area around the infected farm).

Similar Control Zones have also been used in the Scottish salmon farming industry (JGIWG 2000; Stagg 2003). A circle with a radius equal to one tidal excursion is drawn around the centre of each farm. In the absence of on-site water current data or computer modelling studies, the tidal excursions were estimated from existing maps of maximum tidal current speeds during spring tides in Scottish coastal waters. When a farm becomes infected, there is a requirement for simultaneous fallowing and increased fish health surveillance at all farms within its Control Zone. Larger Surveillance Zones (or Management Areas) consist of all salmon farms having overlapping tidal excursion areas, although in a few cases slight overlaps in tidal excursions are allowed between adjacent zones.

METHODS

The site boundaries for fish farms in southwestern New Brunswick were provided by NBDAFA and were entered into a Geographic Information System (MapInfo Professional® 7.0). There were a total of 21 finfish farms within the study area: BMAs 1a, 1b, 2, 3, 4-north, and 7-north (Fig. 1). The results presented for some farms (in BMAs 2, 7, and parts of 3 and 4) have also been included in other reports (Chang et al. 2005a, b). Simple estimates of the zone of influence or water exchange around each farm were made by drawing a 5-km radius circle centred on the farm site, then deleting any land areas which fell within this circle, as well as any water areas which were separated from the farm site by land. If it was known that the fish cages were not located at the middle of a site, the circle was centred over the approximate location of the fish cage cluster. These circular areas were drawn using the MapInfo buffer tool, and are henceforth referred to as buffer zones. The maximum possible area of a 5-km radius buffer zone (i.e. if there were no land areas within the zone) is 78.5 km^2.

More precise estimates of the tidal excursions around farms were made through the use of a three-dimensional particle tracking model (Greenberg et al. 2005) that was customized to our

geographic domain of interest. The geographic domain of the model includes the entire Bay of Fundy and Gulf of Maine. The model estimates the tidal currents by dividing the geographic area into triangles (called finite elements) and by numerically solving the equations of motion at each x,y,z,t grid point within the model domain. When the model is run, a depth profile of the current is calculated at each corner of every triangle every 2.07 s. The circulation model is fully non-linear, has 21 sigma depth levels (reduced in water shallower than 10 m), and has variable horizontal resolution (minimum approximately 50 m). This feature of the finite-element model makes it well suited for covering the wide domain of influence with the required detail in the area of interest needed to resolve local characteristics. The spatial resolution of the model is relatively coarse in the middle of the Gulf of Maine and quite fine in the salmon farming areas of SWNB. The model also simulates wetting and drying of intertidal areas. Although the generic model code has the capability of including boundary forcing using multiple tidal constituents, internal water density and surface winds as current driving forces, the customized model for the SWNB area has only been run using boundary forcing by the principal semi-diurnal lunar tide, the M_2 tide.

Using the model, pseudo-drogues or numerical particles were released from a starting grid located approximately at the centre of each farm or, where known, at the location of the cage cluster (Fig. 1). Particles were released simultaneously from 36 points in a 200 × 200 m grid. In some farms, due to their small size or irregular shape, a few of the particle release points were located slightly outside the site boundaries. The particles were released and maintained at 1 m below the sea surface. Each particle was tracked and its position recorded every 20 min for one tidal cycle (12.42 h). Some particle tracks were shorter than one tidal cycle because the tracks terminated when they hit the shore. For each farm site, particles were released from every grid point at hourly intervals over a 12-h period (for a total of 432 particle releases from each farm) in order to represent conditions over one entire tidal cycle.

In order to estimate the areal extent of one model-derived tidal excursion area, the marine surface area in the vicinity of each farm was divided into a grid of 100 × 100 m square cells. A farm's tidal excursion area was then estimated as the total of all cells visited by at least one particle track from that farm. As a measure of the relative intensity of particle distribution, we calculated the number of particle tracks which passed through each 100 × 100 m cell.

We then examined the influence (due to water circulation) each farm had on other farms, as well as the influence other farms had on each farm. To measure the influence each farm had on other farms, we determined which farm sites (receiving farms) were overlapped (at least partially) by each originating farm's water exchange area (as estimated by a 5-km radius buffer zone and by a model-derived tidal excursion area). To measure the influence that other farms had on each farm, we determined which water exchange areas (from originating farms) overlapped (at least partially) each receiving farm site. We also determined which farms had overlapping water exchange areas.

We compared the interactions among farms using two measures of overlap. The simplest was the presence or absence of overlaps of each water exchange area with farm sites and with water exchange areas. We also used a quantitative measure to estimate the intensity of these overlaps

when using the model-derived tidal excursion areas: we determined the number of particle tracks (of the total 432 particles released from each farm) which overlapped farm sites and farm tidal excursion areas. We used PRIMER 5 software (Clarke and Warwick 1994) to compare the similarity of overlaps among farms by performing cluster analyses using group-average linking of Bray-Curtis similarity coefficients calculated on the presence/absence of overlaps and on the non-transformed numbers of particle tracks which overlapped farm sites and tidal excursion areas.

We also used this methodology to compare the water connectivity with other farms for two proposed locations for a new farm in northern Passamaquoddy Bay.

RESULTS

ESTIMATION OF POTENTIAL INTERACTIONS AMONG FARMS IN PASSAMAQUODDY BAY USING 5-KM RADIUS CIRCULAR BUFFER ZONES

Figure 2 shows the 5-km radius buffer zones of all farms in the Passamaquoddy Bay study area. The figure suggests considerable water exchange among farms throughout the study area. Figures 3-8 show the buffer zones for all farms in each BMA. The areas of the buffer zones ranged from 38.7-73.3 km^2 (Table 1).

The presence or absence of overlaps of buffer zones with farm sites is shown in Table 2. In almost all instances, where one farm's buffer zone overlapped a second farm's site, the second farm's buffer zone overlapped the first farm's site. This is because all buffer zones were based on 5-km radius circles. There were only two instances (2%) out of the total 126 overlaps of buffer zones with farm sites (excluding the 20 overlaps of buffer zones with their originating farm sites) where one farm's buffer zone overlapped a second farm's site, but the second farm's buffer zone did not overlap the first farm's site. These occurred as a result of one aspect of the way that buffer zones were calculated: buffer zones were based on 5-km circles drawn around a point located approximately at the center of each farm site; as a result, there were some cases where the center points of two farms were slightly greater than 5 km apart, but part of the site boundaries of one farm (e.g. a larger farm) extended to within 5 km of the second farm, while the site boundaries of the second farm (e.g. a smaller farm) did not extend to within 5 km of the first farm.

Each buffer zone overlapped an average of 7.3 farm sites within the Passamaquoddy Bay study area (including the originating farm site; see Fig. 9, Table 6). Each buffer zone overlapped an average of 12.2 buffer zones (of farms in the study area, including the originating farm's buffer zone; see Fig. 10, Tables 3 and 7).

There were some overlaps of buffer zones of farms in Passamaquoddy Bay with farm sites (and their buffer zones) located outside of the study area (see Figs. 2 and 5-8). The buffer zones of farms MF-060 and MF-320 (northern BMA 4) overlapped farm sites MF-058 and MF-059 (southern BMA 4), as well as with the buffer zones (but not the farm sites) of several farms in Cobscook Bay Management Zone 2 (see Chang et al. 2005a). The buffer zones of farms MF-039 and MF-040 (northern BMA 7) overlapped farm site MF-038 (southern BMA 7) and several

farm sites in BMA 8, and also overlapped with the buffer zones of all farms in BMAs 7-10 (see Chang et al. 2005b).

The cluster analysis based on the presence or absence of overlaps between buffer zones and farm sites in Passamaquoddy Bay indicated considerable similarity among farms (Fig. 11). No farms were completely separate from all other farms (at 0% similarity). At a similarity level of 4%, there were two clusters: all farms in BMA 1a, plus farm MF-370 (BMA 1b) in one cluster and the other 12 farms in the other cluster. The cluster analysis based on the presence or absence of overlaps among buffer zones indicated very high similarity among all farms in the study area (Fig. 12); there were no completely separate clusters at 0-28% similarity.

DESCRIPTIONS OF MODEL-DERIVED TIDAL EXCURSION AREAS OF FARMS IN PASSAMAQUODDY BAY

Figure 13 shows the model-derived tidal excursion areas (all hourly releases from each farm combined) of all farms in the Passamaquoddy Bay study area. Figures 14-19 show the tidal excursion areas of all farms in each BMA. Figures 20-25 show the tidal excursion areas for each individual farm, including the relative density of particle tracks present in 100 × 100 m grid cells. The tidal excursion areas were much smaller than the 5-km buffer zones, ranging from 0.5-10.1 km^2 (Table 1), and were elongated in shape.

Tidal excursions of farms in BMA 1a (Fig. 20)

The tidal excursion areas of farms in this BMA were small (0.5-1.0 km^2) and elongated in the north-south or northwest-southeast directions. The tidal excursion areas did not overlap any other farm sites or any other tidal excursion areas (other than that of the originating farm), with the exception of the overlap of the tidal excursion area of farm MF-061 with farm site MF-342 and the overlap of the tidal excursion area of farm MF-342 with farm site MF-061.

Tidal excursions of farms in BMA 1b (Fig. 21)

The tidal excursion area of farm MF-370 was small (1.5 km^2), while that of farm MF-377 was larger (5.3 km^2). Both tidal excursion areas were somewhat elongated to the north and south. Neither tidal excursion area overlapped any other farm sites or tidal excursion areas (other than that of the originating farm).

Tidal excursions of farms in BMA 2 (Fig. 22)

Farm MF-255 had a large tidal excursion area (8.76 km^2) which extended mostly northward, then eastward around Macs Island and along the southern shore of Letete Passage. This tidal excursion area did not overlap with any farm sites in BMA 7 (Letete Passage), but did overlap with the tidal excursion areas of farms in BMA 7. Farm MF-256 had a smaller tidal excursion area (2.85 km^2) which extended mostly eastward, then southward, touching farm site MF-042 and continuing along the eastern shore of Deer Island, reaching farm site MF-215 (BMA 6).

Tidal excursions of farms in BMA 3 (Fig. 23)

Farms MF-042, MF-222 and MF-228 had small tidal excursion areas (0.6-1.0 km^2) which extended mainly to the east and west of their farm sites, while that of farm MF-251 was slightly larger (2.1 km^2) and extended mostly to the north and south. The tidal excursion area of farm MF-042 did not overlap any other farm sites (other than its own), while those of farms MF-222 and MF-228 overlapped each other's site. The tidal excursion area of farm MF-251 overlapped farm sites MF-228 and MF-256.

Tidal excursions of farms in the northern part of BMA 4 (Fig. 24)

Farms MF-179 and MF-320 had relatively small tidal excursion areas (1.7-3.1 km^2) which extended to the northeast and southwest of their farm sites. The tidal excursion area of farm MF-179 overlapped farm sites MF-320 and MF-060 (to the southwest), while that of MF-320 overlapped farm sites MF-179 to the northeast and MF-060 to the southwest. The tidal excursion area of farm MF-060 was large (10.1 km^2), extending north through farm sites MF-060 and MF-320 and touching farm site MF-179, and extending south as far as Moose Island, Maine, overlapping farm site IAFI HP and approaching very close to two other Moose Island farm sites (see Chang et al. 2005a).

Tidal excursions of farms in the northern part of BMA 7 (Fig. 25)

The two farms in the northern part of BMA 7 (MF-039 and MF-040) had large tidal excursion areas (8.2-8.9 km^2) which extended southeast along the mainland shore of Letete Passage, reaching the mouths of Back Bay and Bliss Harbour, but not extending far into Passamaquoddy Bay. The tidal excursion area of farm MF-039 overlapped farm site MF-040. The tidal excursion area of farm MF-040 overlapped farm site MF-039, as well as two farm sites located outside the study area – site MF-038 in southern BMA 7 and site MF-276 in BMA 8 (see also Chang et al. 2005b).

ESTIMATION OF POTENTIAL INTERACTIONS AMONG FARMS IN PASSAMAQUODDY BAY USING MODEL-DERIVED TIDAL EXCURSION AREAS

The presence or absence of overlaps of tidal excursion areas with farm sites for the 20 farms within the Passamaquoddy bay study area is shown in Table 4. There were 15 overlaps of tidal excursion areas with other farm sites (excluding the 20 overlaps of tidal excursion areas with their originating farm sites), of which there were three instances (20%) where one farm's tidal excursion area overlapped a second farm's site, but the second farm's tidal excursion area did not overlap the first farm's site.

Each tidal excursion area overlapped an average of 1.8 farm sites within the Passamaquoddy Bay study area (including the originating site; see Fig. 26, Table 8). Most of the overlaps were with farms within the same BMA; only farms in BMAs 2 and 3 overlapped farm sites in another BMA.

Each farm site was overlapped by an average of 1.8 tidal excursion areas within the Passamaquoddy Bay study area (including the receiving farm's tidal excursion area; see Fig. 27, Table 8). Most of the overlapping tidal excursion areas were from farms in the same BMA as the receiving farm; only farms in BMAs 2 and 3 were overlapped by the tidal excursion areas of farms in another BMA.

There were more overlaps among tidal excursion areas, compared to the numbers of overlaps of tidal excursion areas with farm sites. The tidal excursion areas of farms in BMAs 1a and 1b were only overlapped by tidal excursion areas of farms in their own BMA; the tidal excursion areas of some farms in other BMAs overlapped with tidal excursion areas of farms in other BMAs within the study area (Table 5). Each tidal excursion area overlapped with an average of 2.3 tidal excursion areas from farms within the Passamaquoddy Bay study area (including each tidal excursion area's overlap with itself; see Fig. 28, Table 9).

The cluster analysis based on the number of farm sites overlapped by each farm's tidal excursion area (Fig. 29) showed that at 0% similarity, there were eight farms which were completely isolated from all others, there were two clusters of two farms each (MF-061 with MF-342 in BMA 1a in one cluster and MF-039 with MF-040 in BMA 7 in the other), there was one cluster of the three farms in the northern part of BMA 4, and there was one cluster of the four farms in BMA 3 plus farm MF-256 (BMA 2). The cluster analysis, based on the number of farm tidal excursion areas overlapping each farm site (Fig. 30), produced a similar clustering pattern to that in Fig. 29.

The cluster analysis based on the presence or absence of overlaps among tidal excursion areas (Fig. 31) showed that seven farms were completely isolated from all others, there was one cluster of two farms (MF-061 and MF-342 in BMA 1a), and one cluster of all other farms. At 5% similarity, the large cluster could be separated into two smaller clusters: the three farms in the northern part of BMA 4, plus all farms in BMA 3, except for MF-042, in one cluster, and all farms in BMA 2 and the northern part of BMA 7, plus MF-042, in the other cluster.

The cluster analysis based, on the intensity of overlap of tidal excursion areas with farm sites (as measured by the number of particle tracks that overlapped farm sites; see Fig. 32), showed lower similarity than Fig. 29, and larger numbers of separate clusters: at 0-29% similarity there were nine farms which were completely isolated from all others, there were four clusters of two farms each (MF-256 with MF-251; MF-061 with MF-342; MF-222 with MF-228; and MF-039 with MF-040), and there was one cluster of the three farms in the northern part of BMA 4. The cluster analysis, based on the intensity of overlap among tidal excursion areas (as measured by the number of particle tracks that overlapped tidal excursion areas; see Fig. 33), showed much lower similarity that in Fig. 31. At 0-26% similarity, there were seven farms which were completely isolated from all others; there were two clusters of two farms each (MF-222 with MF-228 and MF-061 with MF-342); and three clusters of three farms each.

There were some overlaps of tidal excursion areas of farms in Passamaquoddy Bay with farm sites located outside of the bay. The tidal excursion area of farm MF-060 (northern BMA 4) overlapped farm site IAFI HP (Moose Island, Maine), although only 17 particles (of 432) released from farm MF-060 overlapped site IAFI HP. The tidal excursion area of farm MF-040

(northern BMA 7) overlapped farm sites MF-038 (southern BMA 7) and MF-276 (BMA 8); only one particle (of 432) released from farm MF-040 overlapped site MF-038, while no particles overlapped site MF-276 (although two particles approached within 35 m of the site, with the result that the tidal excursion area drawn around these particle tracks slightly overlapped this farm site).

There were also some overlaps of tidal excursion areas of farms in Passamaquoddy Bay with tidal excursion areas of farms located outside of the bay. The tidal excursion area of farm MF-060 (northern BMA 4) overlapped with the tidal excursion areas of three farms off Moose Island, Maine (IAFI JK, TIFI CC, and IAFI HP). The tidal excursion area of farm MF-320 (northern BMA 4) overlapped with the tidal excursion areas of all farms in southern BMA 4 and most farms in BMA 5. The tidal excursion areas of farms MF-039 and MF-040 (northern BMA 7) overlapped with the tidal excursion areas of farms MF-038 (southern BMA 7), MF-037 (BMA 8) and MF-276 (BMA 8).

PROPOSED OPTIONS FOR THE LOCATION OF A NEW SALMON FARM IN NORTHERN PASSAMAQUODDY BAY

The 5-km radius buffer zone method indicated few differences, in terms of predicted water connectivity with other farms, between sites A and B; both sites' buffer zones overlapped all existing farm sites (and their buffer zones) in BMA 1a, as well as farm MF-370 (BMA 1b). Neither site's model-derived tidal excursion area overlapped any existing farm sites, but the tidal excursion area of site A overlapped with the tidal excursion area of farm MF-084, while the tidal excursion area of site B did not overlap with any tidal excursion areas of existing farms (Fig. 34).

DISCUSSION

The simple approach using 5-km radius buffer zones to estimate water exchange areas predicts considerable water exchange among finfish farms in Passamaquoddy Bay. If the speculation that ISA can be spread through the water is correct, then this suggests the need for collaboration in the fish health management of all salmon farms in this area, i.e. all farms in the study area should be in one management zone, with synchronization of smolt entry, fallowing, and fish health management of all farms.

Because the model results generally agree with field data (Page et al. 2004), we expect that the model-derived tidal excursion areas are more accurate predictors of water exchange areas than the circular buffer zones. The model tidal excursion areas are much smaller than the 5-km radius buffer zones and are not circular. Consequently, the model tidal excursion areas predict much less water exchange among most farms, especially for farms in BMAs 1a and 1b. These appear to be isolated from farms in other BMAs, and are also mostly isolated from other farms in the same BMA. There are, however, overlaps (using model-derived tidal excursion areas) among farms situated along the northwest shore of Deer Island and Macs Island in BMAs 2, 3, and 4. This suggests that these BMAs should be combined into one management zone.

In another report we used similar methods to examine the water connectivity between farms in the mainland growing area of Back Bay, Bliss Harbour, and Lime Kiln Bay, and farms in the

northern Deer Island area (see Chang et al. 2005b). In that report, we showed that farm MF-255 in BMA 2 and, to a lesser extent, farms in BMA 7 (Letete Passage) provided water connectivity between these two farming regions (based on model-derived tidal excursion areas). Farm MF-255 has since been removed and farm MF-038 (southern BMA 7) is growing only cod and haddock, so this water connectivity among salmon farms has been largely broken. The model results, however, predict that there is still a small amount of water exchange (during one tidal excursion) between some farms in Passamaquoddy Bay and farms in other salmon growing areas: from farm MF-040 in northern BMA 7 to farm MF-276 in BMA 8 (Back Bay); from farm MF-256 in BMA 2 (Macs Island area) to farm MF-215 in BMA 6 (eastern Deer Island area); and from farm MF-060 in BMA 4 (northwestern Deer Island area) to farm IAFI HP off the northeast shore of Moose Island, Maine.

The two methods produced quite different results when used to predict the potential for water exchange with other farms for two proposed locations for a new farm in northern Passamaquoddy Bay. The 5-km radius buffer zones suggested no differences between the two locations: both sites' buffer zones overlapped several existing farm sites. The model-derived tidal excursion areas, however, indicated much less water connectivity with existing farms for both sites, and that site B would be more isolated from existing farms than site A.

It must be noted that the tidal excursions as predicted by the model are determined completely by the M_2 tide. Although the M_2 component is the major component of the tide in this area, other factors such as wind and spring-neap tides do play a role and when these are included in the model, the particle trajectories and exposure maps will be modified to some degree, probably increasing the sizes of the predicted tidal excursion areas.

ACKNOWLEDGEMENTS

Funding for this project was provided by Fisheries and Oceans Canada (DFO) and DFO and industry contributions to the Aquaculture Collaborative Research and Development Program (ACRDP). The study was conducted in collaboration with the New Brunswick Department of Agriculture, Fisheries and Aquaculture (NBDAFA) and the New Brunswick Salmon Growers' Association. We especially wish to thank M. Beattie, S. McGeachy, and G. Smith of NBDAFA.

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Table 1. Water exchange areas of finfish farms in Passamaquoddy Bay. Water exchange areas were estimated by two methods: 5-km radius circular buffer zones (excluding land and water areas cut off from the originating farm site by land) and model-derived tidal excursion areas. BMA = Bay Management Area.

Farm site	5-km radius buffer zone (km^2)	Model tidal excursion area (km^2)	Farm site	5-km radius buffer zone (km^2)	Model tidal excursion area (km^2)
BMA 1a			**BMA 3**		
MF-061	46.0	0.8	MF-042	60.2	1.0
MF-084	56.6	0.9	MF-222	63.2	0.6
MF-181	52.7	0.5	MF-228	56.6	0.7
MF-214	47.5	1.0	MF-251	51.3	2.1
MF-290	56.5	0.7	Mean ± SD	57.8 ± 4.4	1.1 ± 0.6
MF-337	49.1	1.0			
MF-342	38.7	0.7	**BMA 4 (in part)**		
Mean ± SD	49.6 ± 6.4	0.8 ± 0.2	MF-060	45.8	10.1
			MF-179	54.2	3.1
BMA 1b			MF-320	46.1	1.7
MF-370	73.3	1.5	Mean ± SD	48.7 ± 4.7	5.0 ± 4.5
MF-377	68.6	5.3			
Mean ± SD	70.9 ± 3.3	3.4 ± 2.7	**BMA 7 (in part)**		
			MF-039	48.9	8.2
BMA 2			MF-040	46.7	8.9
MF-255	60.7	8.8	Mean ± SD	47.8 ± 1.5	8.6 ± 0.5
MF-256	63.5	2.9			
Mean ± SD	62.1 ± 2.0	5.8 ± 4.2	**All Passamaquoddy Bay**		
			Mean ± SD	54.3 ± 8.7	3.0 ± 3.3

Table 2. Overlaps (indicated by shaded squares) of 5-km radius buffer zones with finfish farm sites in Passmaquoddy Bay, SWNB.

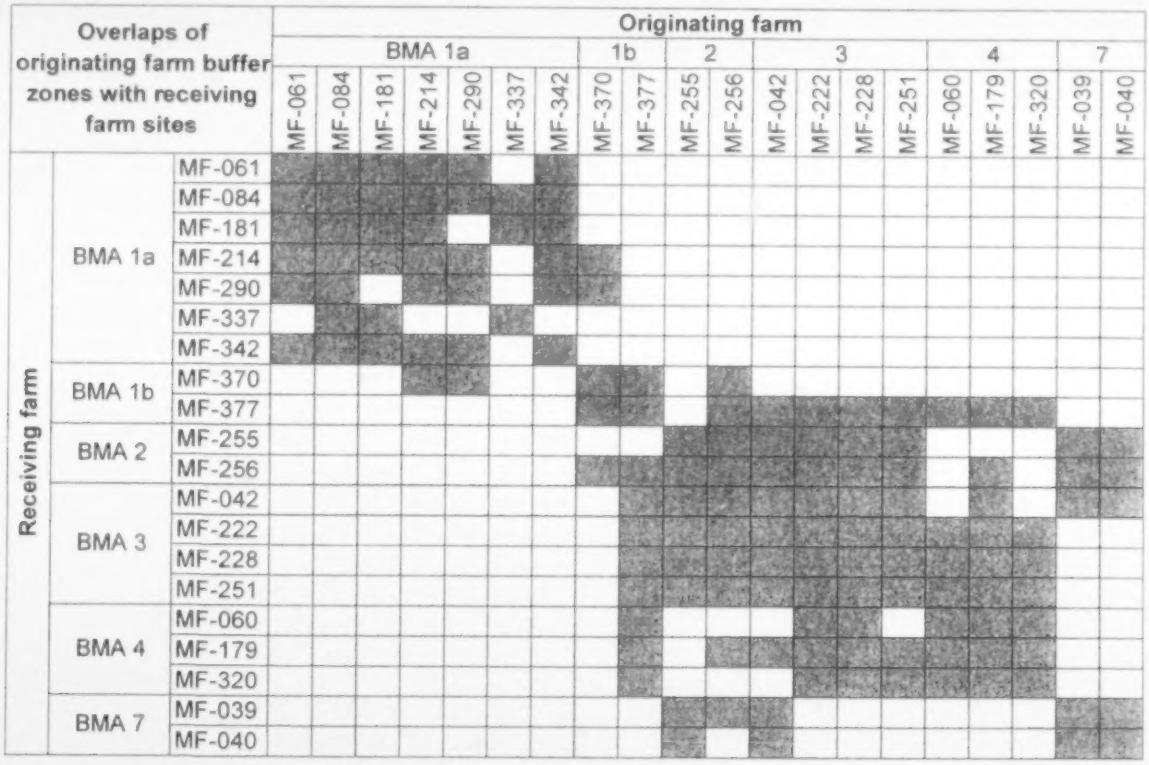


Table 3. Overlaps (indicated by shaded squares) among 5-km radius buffer zones of finfish farms in Passamaquoddy Bay, SWNB.

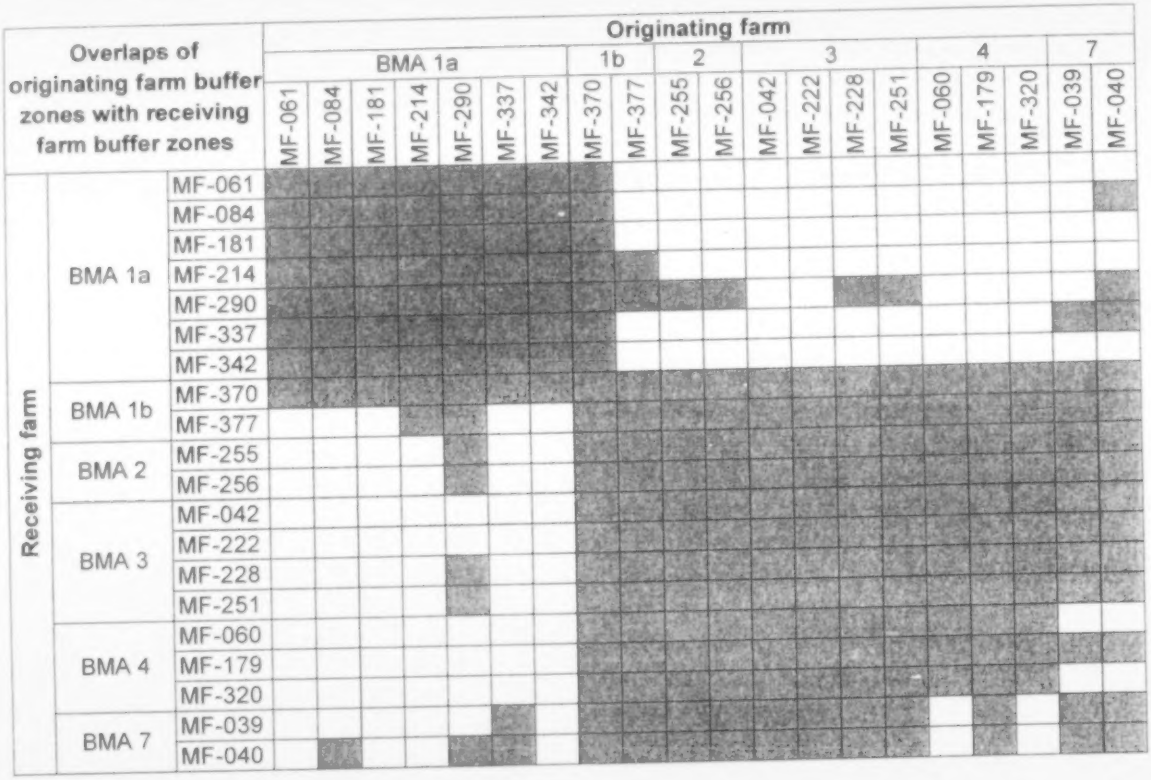


Table 4. Overlaps (indicated by shaded squares) of model-derived tidal excursion areas with finfish farm sites in Passamaquoddy Bay, SWNB.

Overlaps of originating farm tidal excursion areas with receiving farm sites			Originating farm																					
			BMA 1a							1b		2		3				4			7			
			MF-061	MF-084	MF-181	MF-214	MF-290	MF-337	MF-342	MF-370	MF-377	MF-255	MF-256	MF-042	MF-222	MF-228	MF-251	MF-060	MF-179	MF-320	MF-039	MF-040
Receiving farm	BMA 1a	MF-061	■						■															
		MF-084		■																				
		MF-181			■																			
		MF-214				■																		
		MF-290					■																	
		MF-337						■																
		MF-342	■						■															
	BMA 1b	MF-370								■														
		MF-377									■													
	BMA 2	MF-255										■												
		MF-256											■	■			■							
	BMA 3	MF-042											■	■										
		MF-222													■	■								
		MF-228													■	■	■							
		MF-251															■							
	BMA 4	MF-060																■	■	■				
		MF-179																■	■	■				
		MF-320																■	■	■				
	BMA 7	MF-039																			■	■		
		MF-040																			■	■		

Table 5. Overlaps (indicated by shaded squares) among model-derived tidal excursion areas of finfish farms in Passamaquoddy Bay, SWNB.

Overlaps of originating farm tidal excursion areas with receiving farm tidal excursion areas			Originating farm																				
			BMA 1a							1b		2		3				4			7	
			MF-061	MF-084	MF-181	MF-214	MF-290	MF-337	MF-342	MF-370	MF-377	MF-255	MF-256	MF-042	MF-222	MF-228	MF-251	MF-060	MF-179	MF-320	MF-039	MF-040
Receiving farm	BMA 1a	MF-061	■						■													
		MF-084		■																		
		MF-181			■																	
		MF-214				■																
		MF-290					■															
		MF-337						■														
		MF-342	■						■													
	BMA 1b	MF-370								■												
		MF-377									■											
	BMA 2	MF-255										■	■								■	■
		MF-256										■	■	■			■					
	BMA 3	MF-042											■	■								
		MF-222													■	■						
		MF-228													■	■	■					
		MF-251											■			■	■		■			
	BMA 4	MF-060																■	■	■		
		MF-179															■	■	■	■		
		MF-320																■	■	■		
	BMA 7	MF-039										■									■	■
		MF-040										■									■	■

Table 6. Mean numbers of overlaps of 5-km radius buffer zones (from originating farms) with farm sites (receiving farms), by Bay Management Area (BMA), for farms in Passmaquoddy Bay. The numbers are means (± SD) of all originating farms in each BMA, including the overlap of each buffer zone with its own farm site.

BMA of originating farms	BMA of receiving farms						
	BMA 1a (n=7)	BMA 1b (n=2)	BMA 2 (n=2)	BMA 3 (n=4)	BMA 4 (n=3)	BMA 7 (n=2)	All (n=20)
1a	5.6 ± 1.3	0.3 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.9 ± 1.4
1b	1.0 ± 1.4	2.0 ± 0.0	1.0 ± 0.0	2.0 ± 2.8	1.5 ± 2.1	0.0 ± 0.0	7.5 ± 3.5
2	0.0 ± 0.0	1.0 ± 1.4	2.0 ± 0.0	4.0 ± 0.0	0.5 ± 0.7	1.5 ± 0.7	9.0 ± 1.4
3	0.0 ± 0.0	1.0 ± 0.0	2.0 ± 0.0	4.0 ± 0.0	2.3 ± 1.0	0.5 ± 1.0	9.8 ± 0.5
4	0.0 ± 0.0	1.0 ± 0.0	0.3 ± 0.6	3.3 ± 0.6	3.0 ± 0.0	0.0 ± 0.0	7.7 ± 1.2
7	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.0	1.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.0	5.0 ± 0.0

Table 7. Mean numbers of overlaps among 5-km radius buffer zones, by Bay Management Area (BMA), for finfish farms in Passamaquoddy Bay. The numbers are means (± SD) of all originating farms in each BMA, including the overlap of each buffer zone with itself.

BMA of originating farms	BMA of receiving farms						
	BMA 1a (n=7)	BMA 1b (n=2)	BMA 2 (n=2)	BMA 3 (n=4)	BMA 4 (n=3)	BMA 7 (n=2)	All (n=20)
1a	7.0 ± 0.0	1.3 ± 0.5	0.3 ± 0.8	0.3 ± 0.8	0.0 ± 0.0	0.6 ± 0.8	9.4 ± 2.2
1b	4.5 ± 3.5	2.0 ± 0.0	2.0 ± 0.0	4.0 ± 0.0	3.0 ± 0.0	2.0 ± 0.0	17.5 ± 3.5
2	1.0 ± 0.0	2.0 ± 0.0	2.0 ± 0.0	4.0 ± 0.0	3.0 ± 0.0	2.0 ± 0.0	14.0 ± 0.0
3	0.5 ± 0.6	2.0 ± 0.0	2.0 ± 0.0	4.0 ± 0.0	3.0 ± 0.0	2.0 ± 0.0	13.5 ± 0.6
4	0.0 ± 0.0	2.0 ± 0.0	2.0 ± 0.0	4.0 ± 0.0	3.0 ± 0.0	0.7 ± 1.2	11.7 ± 1.2
7	2.0 ± 1.4	2.0 ± 0.0	2.0 ± 0.0	4.0 ± 0.0	1.0 ± 0.0	2.0 ± 0.0	13.0 ± 1.4

Table 8. Mean numbers of overlaps between model-derived tidal excursion areas and finfish farm sites, by Bay Management Area (BMA), for farms in Passamaquoddy Bay. Top: numbers of farm sites (receiving farms) overlapped by each tidal excursion area (from originating farm). Bottom: numbers of tidal excursion areas (from originating farms) overlapping each farm site (receiving farm). The numbers are means (± SD) of all farms in each BMA, including the overlap of each tidal excursion area with its own farm site.

BMA of originating farms	BMA of receiving farms						
	BMA 1a (n=7)	BMA 1b (n=2)	BMA 2 (n=2)	BMA 3 (n=4)	BMA 4 (n=3)	BMA 7 (n=2)	All (n=20)
1a	1.3 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.5
1b	0.0 ± 0.0	1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0
2	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0	0.5 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.7
3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.5	1.8 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.8
4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 0.0	0.0 ± 0.0	3.0 ± 0.0
7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.0	2.0 ± 0.0

BMA of receiving farms	BMA of originating farms						
	BMA 1a (n=7)	BMA 1b (n=2)	BMA 2 (n=2)	BMA 3 (n=4)	BMA 4 (n=3)	BMA 7 (n=2)	All (n=20)
1a	1.3 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.5
1b	0.0 ± 0.0	1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0
2	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0	0.5 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.7
3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.5	1.8 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.8
4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 0.0	0.0 ± 0.0	3.0 ± 0.0
7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.0	2.0 ± 0.0

Table 9. Mean numbers of overlaps among model-derived tidal excursion areas, by Bay Management Area (BMA), for finfish farms in Passamaquoddy Bay. The numbers are means (± SD) of all originating farms in each BMA, including the overlap of each tidal excursion area with itself.

BMA of originating farms	BMA of receiving farms						
	BMA 1a (n=7)	BMA 1b (n=2)	BMA 2 (n=2)	BMA 3 (n=4)	BMA 4 (n=3)	BMA 7 (n=2)	All (n=20)
1a	1.3 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.5
1b	0.0 ± 0.0	1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0
2	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.0	1.0 ± 1.4	0.0 ± 0.0	1.0 ± 1.4	4.0 ± 0.0
3	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.6	2.0 ± 0.8	0.3 ± 0.5	0.0 + 0.0	2.3 ± 1.0
4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.6	3.0 ± 0.0	0.0 ± 0.0	3.3 ± 0.6
7	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.0	3.0 ± 0.0

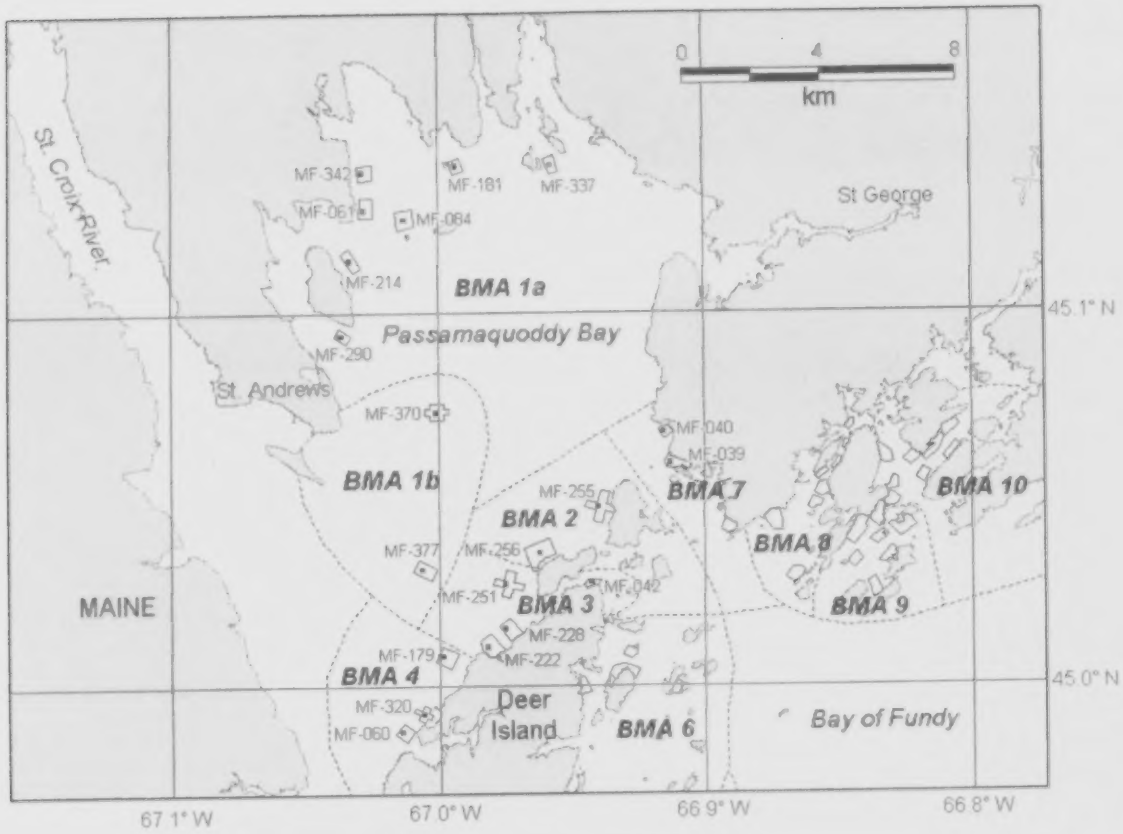


Fig. 1. Map of the Passamaquoddy Bay area, SWNB, showing Bay Management Areas (BMAs), finfish farm sites (white polygons) and starting grid locations (small black squares inside farm sites) for model particle releases from farms in BMAs 1a, 1b, 2, 3, 4-north, and 7-north.

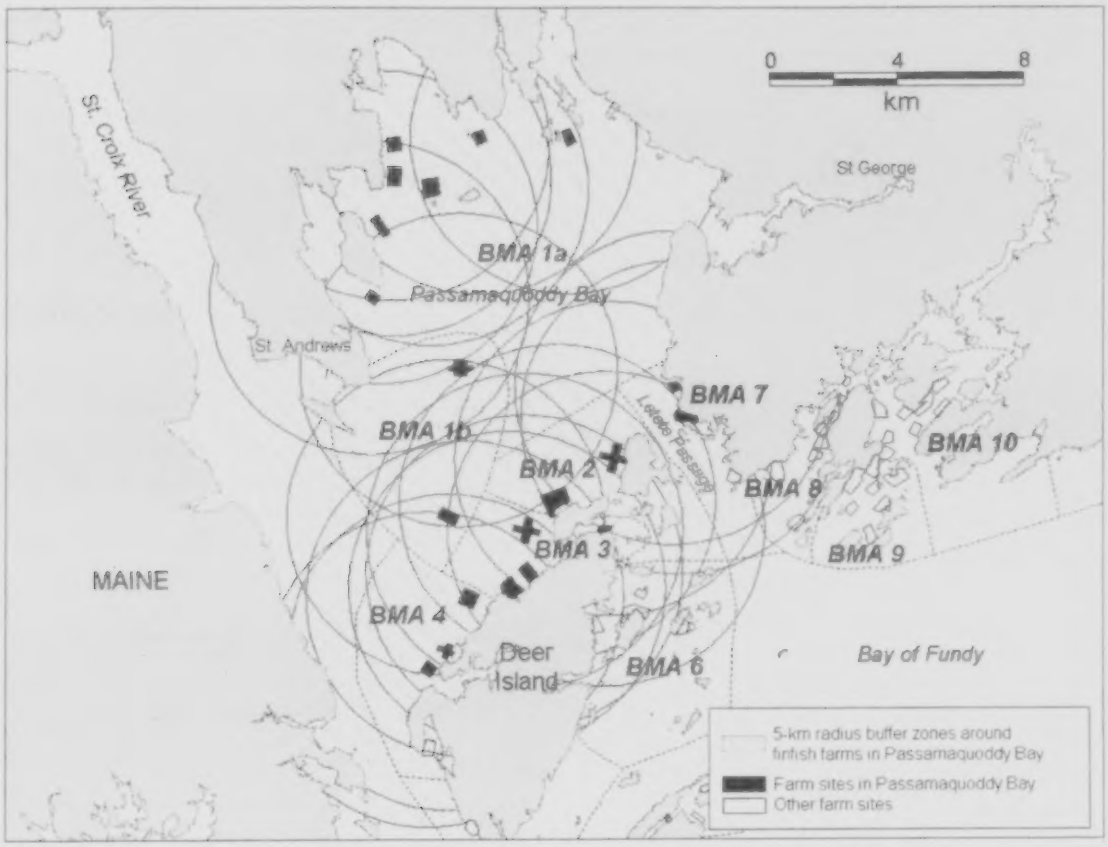


Fig. 2. Map showing 5-km radius buffer zones of all finfish farms in Passamaquoddy Bay.

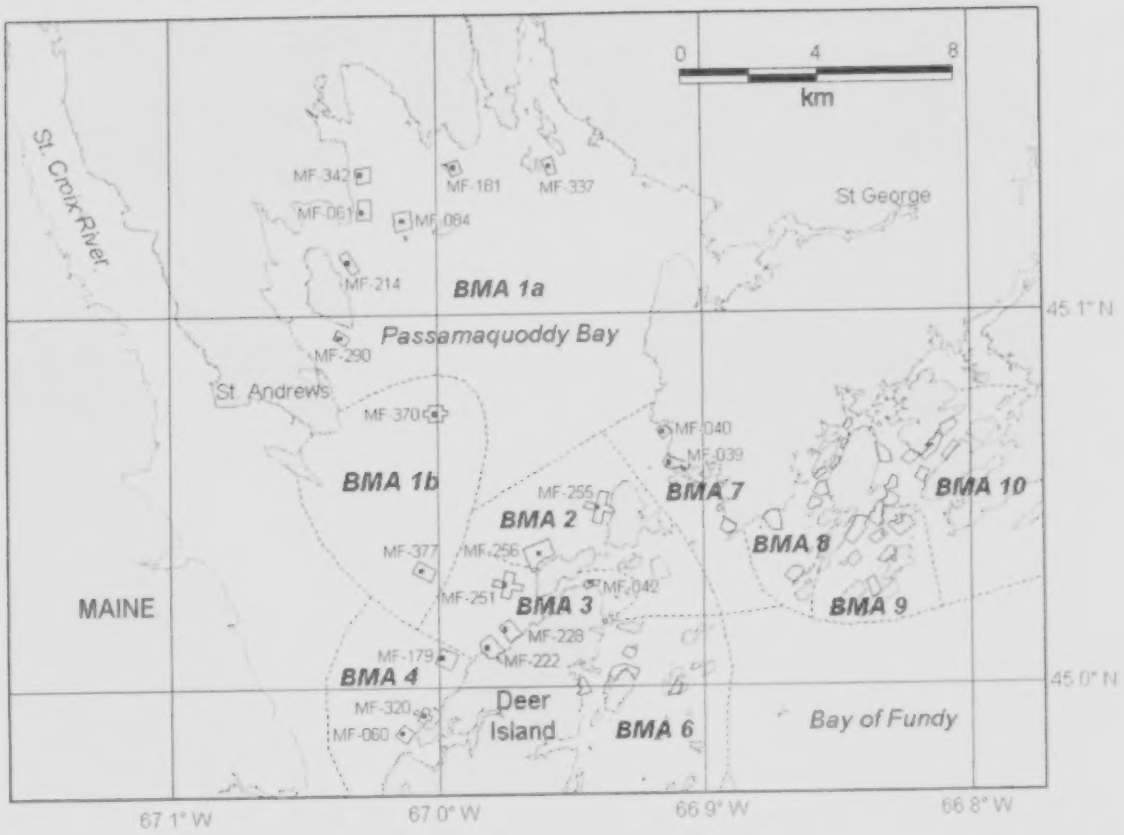
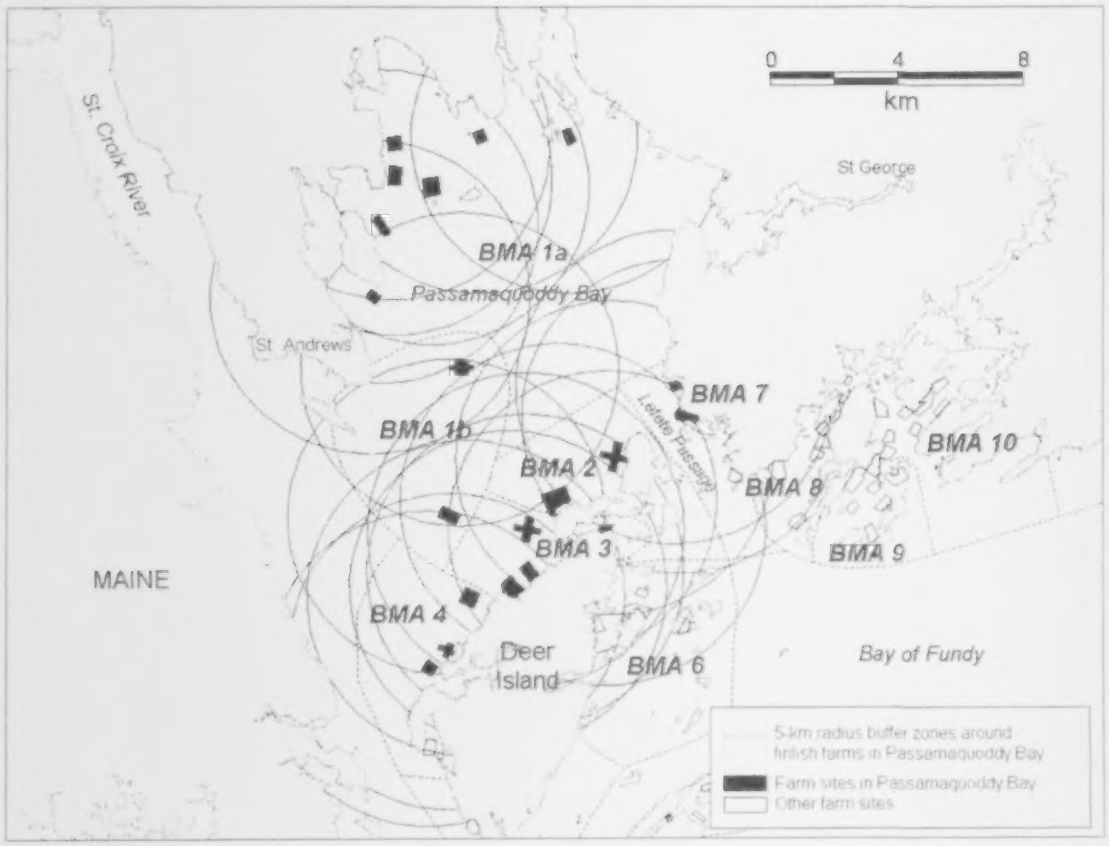


Fig. 1. Map of the Passamaquoddy Bay area, SWNB, showing Bay Management Areas (BMAs), finfish farm sites (white polygons) and starting grid locations (small black squares inside farm sites) for model particle releases from farms in BMAs 1a, 1b, 2, 3, 4-north, and 7-north.



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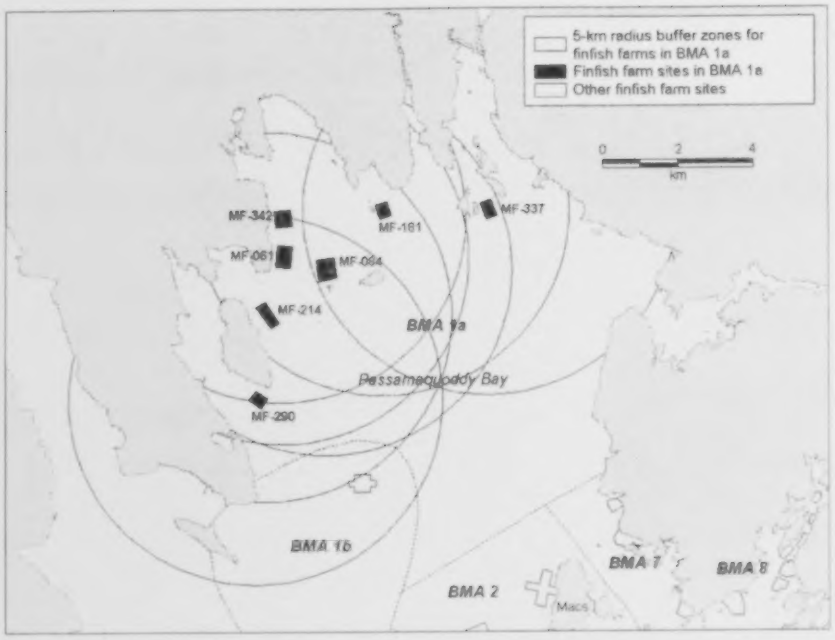


Fig. 3. Map showing 5-km radius buffer zones of finfish farms in BMA 1a, northern Passamaquoddy Bay.

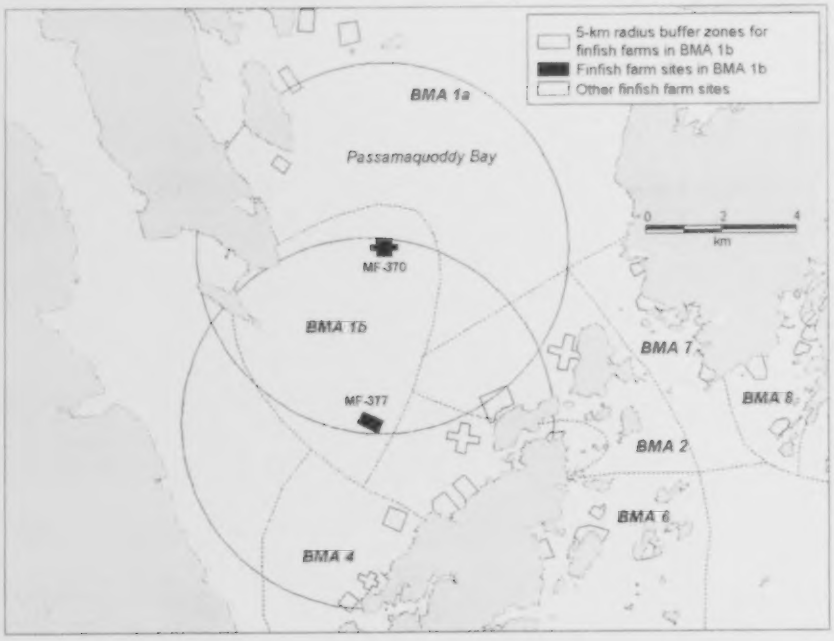


Fig. 4. Map showing 5-km radius buffer zones of finfish farms in BMA 1b, central Passamaquoddy Bay.

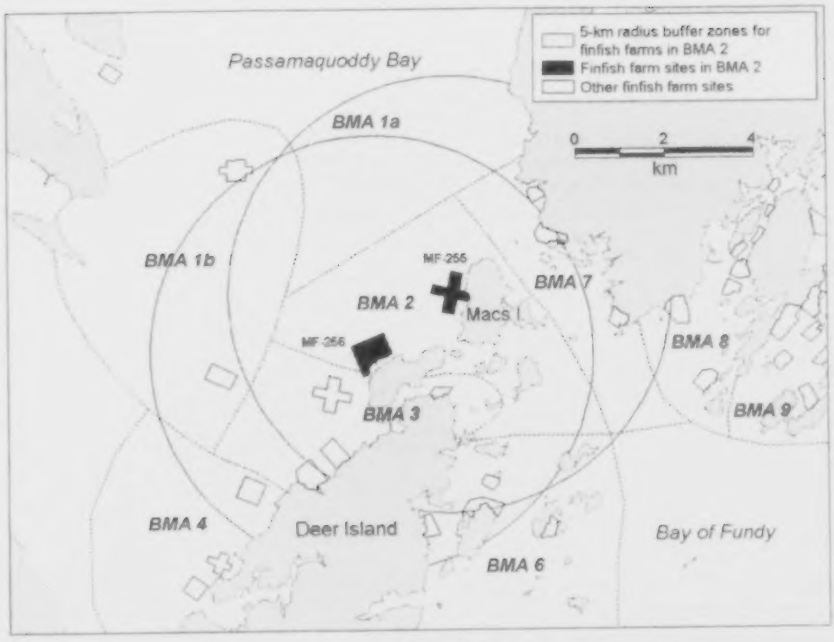


Fig. 5. Map showing 5-km radius buffer zones of finfish farms in BMA 2, Macs Island area.

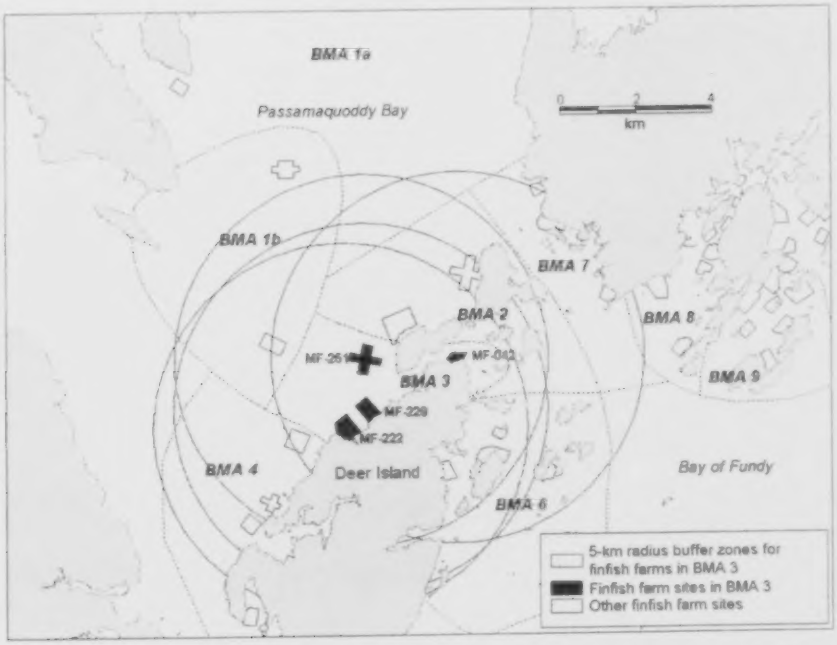


Fig. 6. Map showing 5-km radius buffer zones of finfish farms in BMA 3, northern Deer Island area.

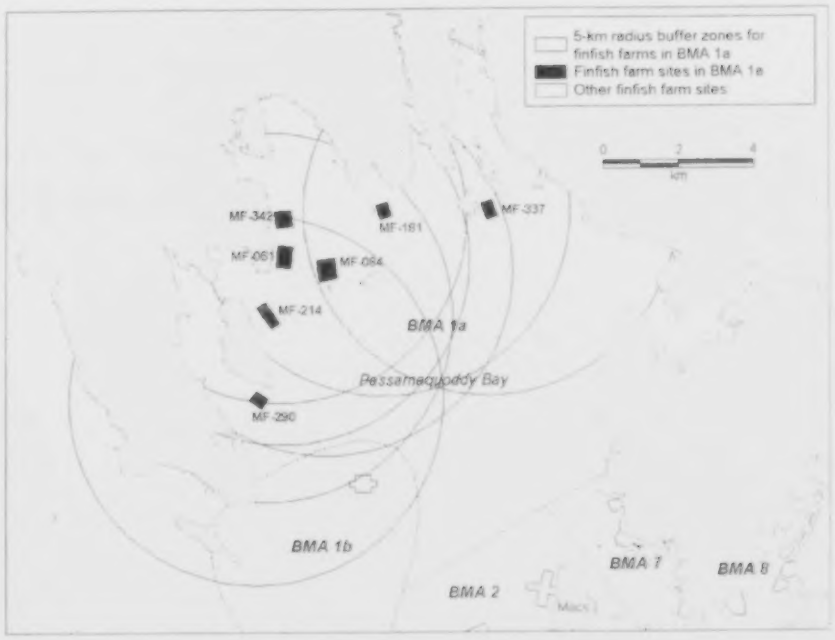


Fig. 3. Map showing 5-km radius buffer zones of finfish farms in BMA 1a, northern Passamaquoddy Bay.

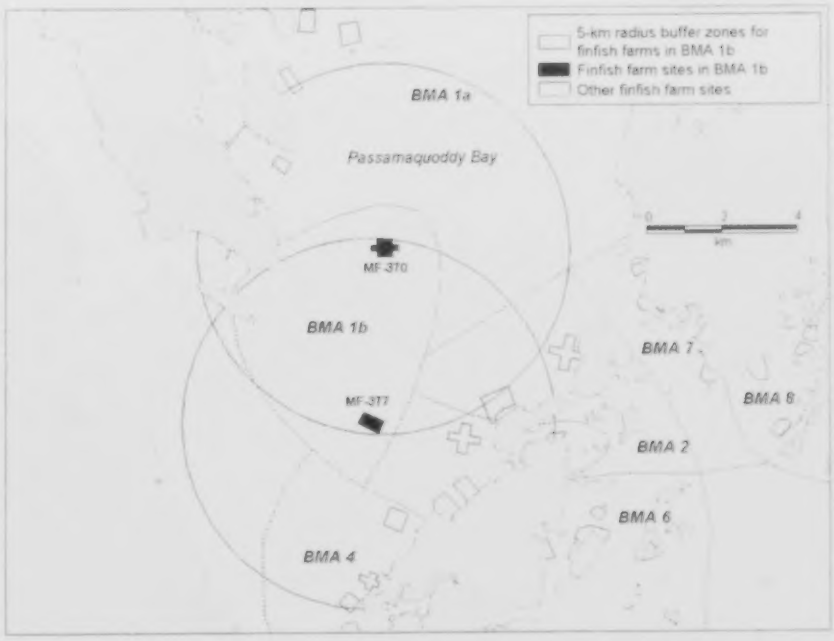


Fig. 4. Map showing 5-km radius buffer zones of finfish farms in BMA 1b, central Passamaquoddy Bay.

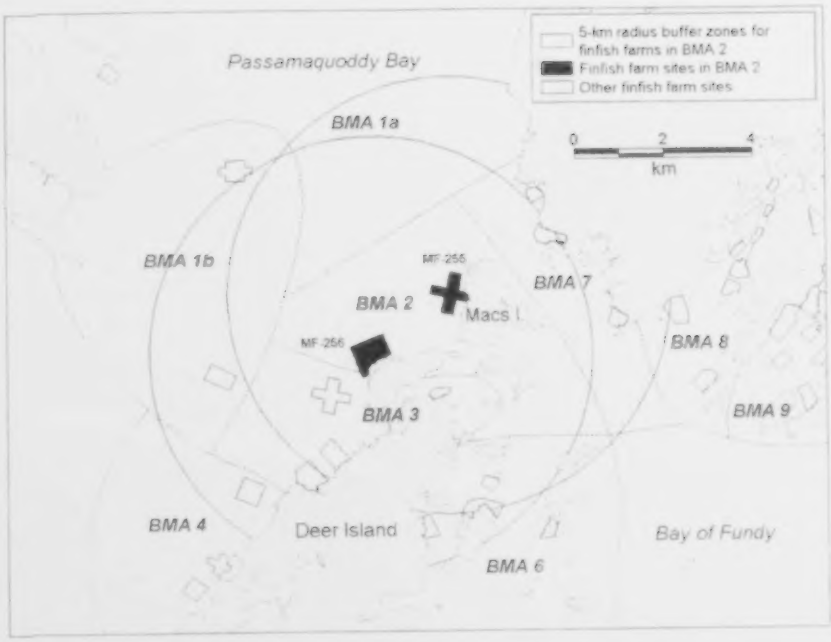


Fig. 5. Map showing 5-km radius buffer zones of finfish farms in BMA 2, Macs Island area.

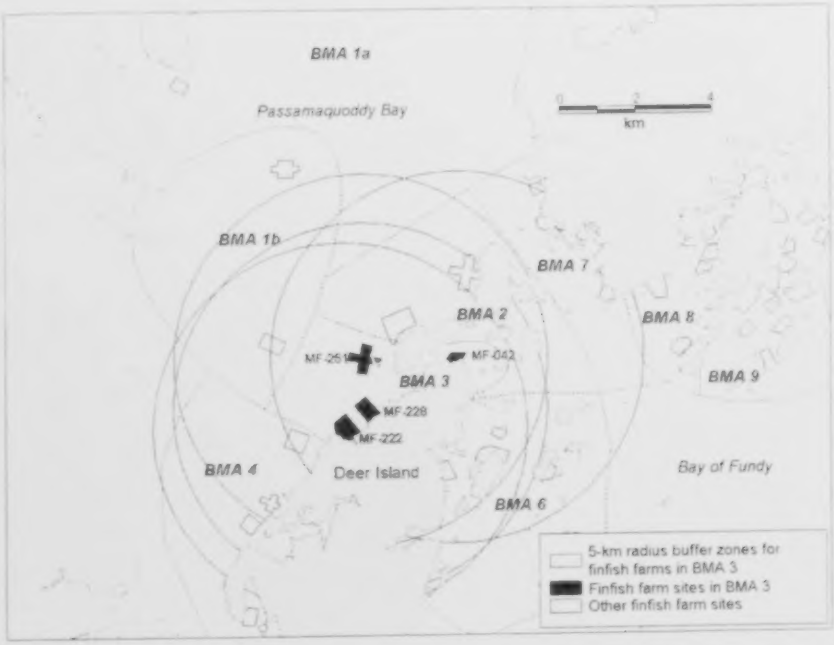


Fig. 6. Map showing 5-km radius buffer zones of finfish farms in BMA 3, northern Deer Island area.

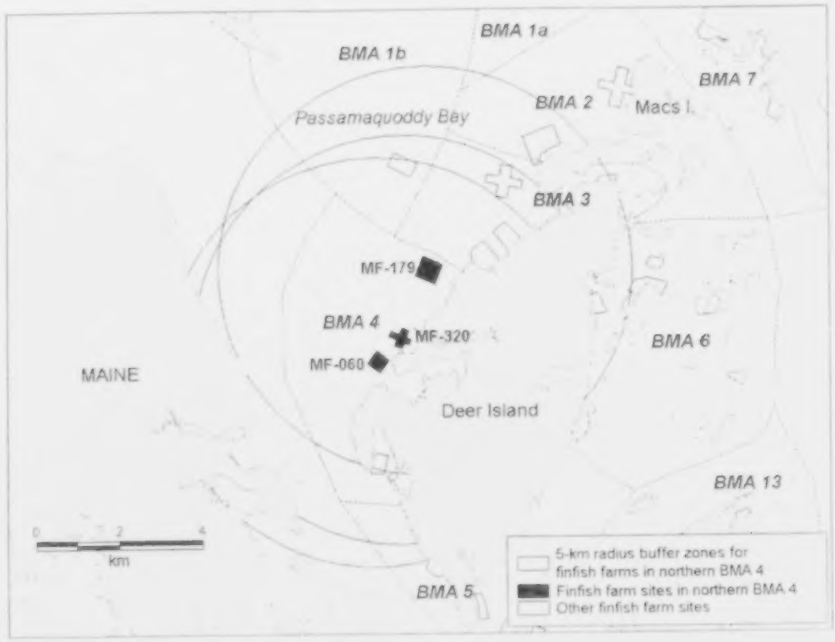


Fig. 7. Map showing 5-km radius buffer zones of finfish farms in the northern part of BMA 4, western Deer Island area.

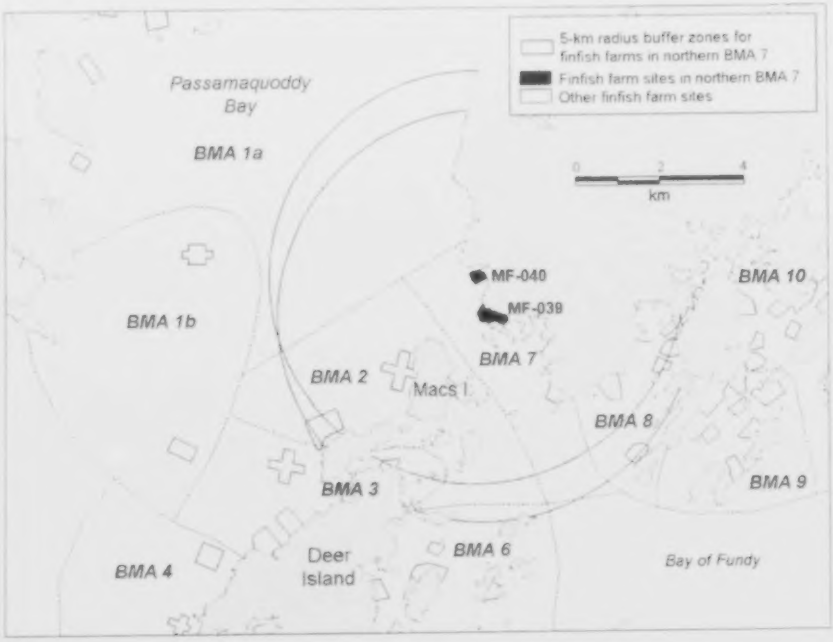


Fig. 8. Map showing 5-km radius buffer zones of finfish farms in the northern part of BMA 7, Letete Passage.

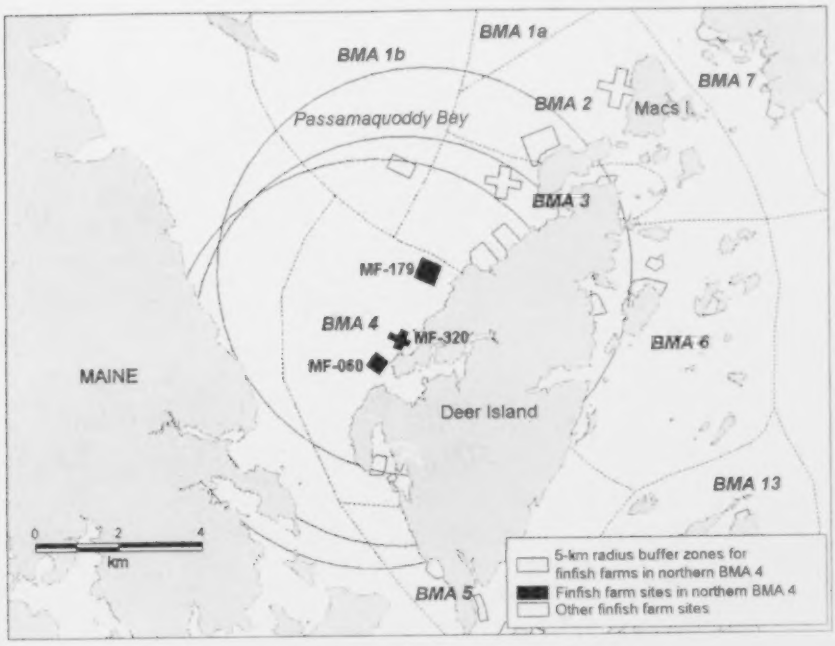


Fig. 7. Map showing 5-km radius buffer zones of finfish farms in the northern part of BMA 4, western Deer Island area.

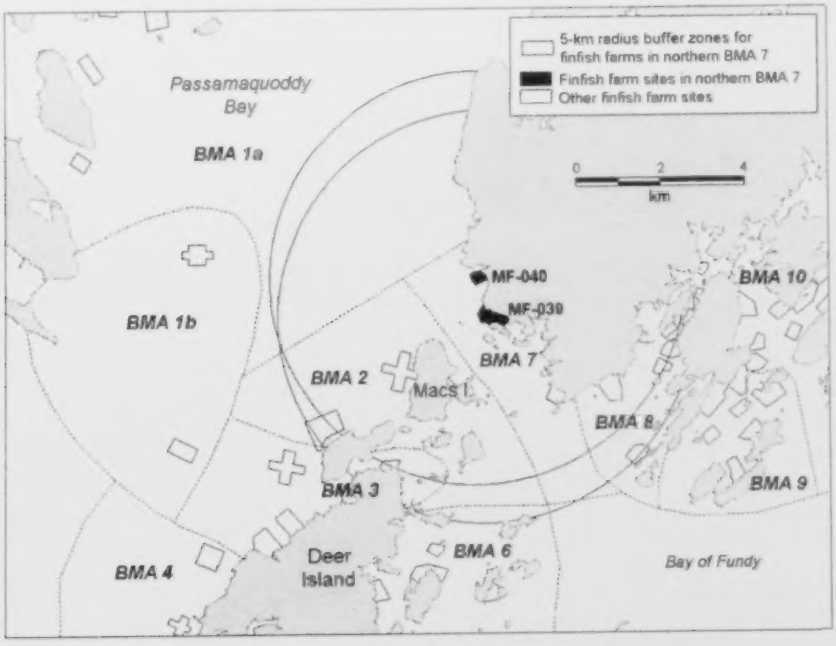


Fig. 8. Map showing 5-km radius buffer zones of finfish farms in the northern part of BMA 7, Letete Passage.

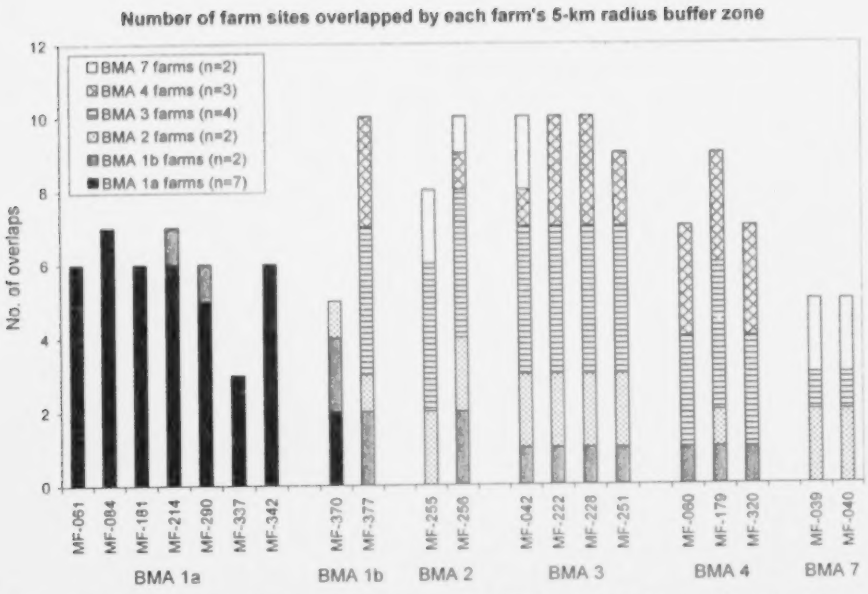


Fig. 9. Number of finfish farm sites overlapped by each farm's 5-km radius buffer zone in Passamaquoddy Bay. The numbers include overlaps with the originating farm.

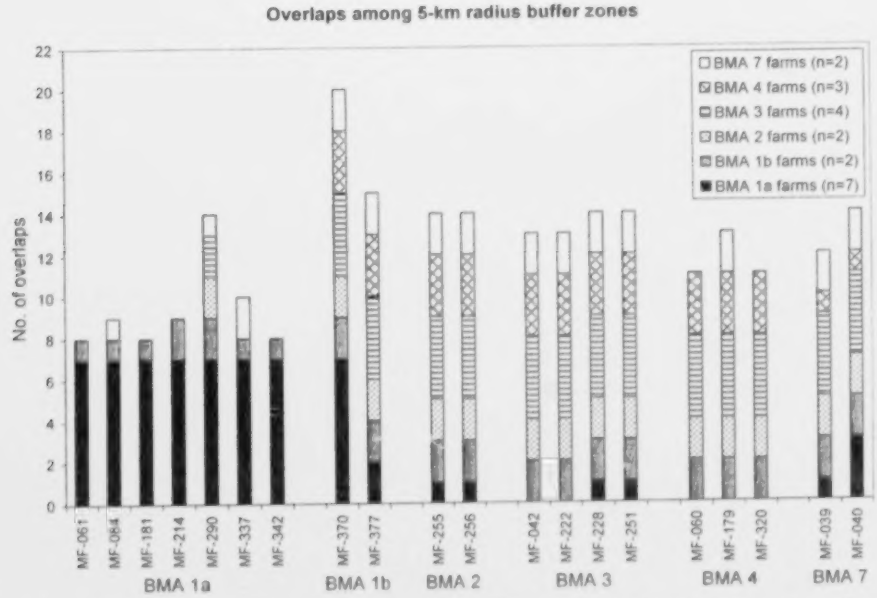


Fig. 10. Number of overlaps among 5-km radius buffer zones of finfish farms in Passamaquoddy Bay. The numbers include overlaps with the originating farm.

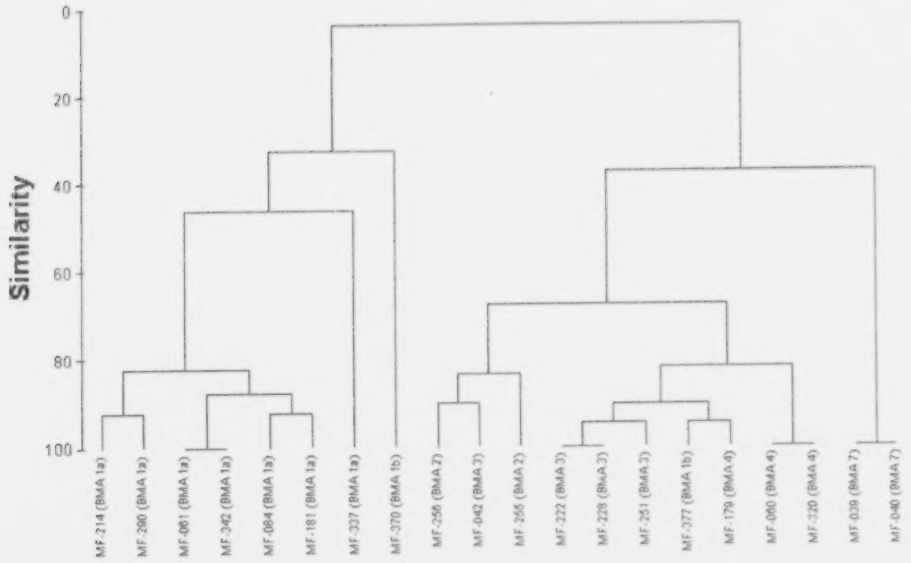


Fig. 11. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps of each farm's 5-km radius buffer zone with finfish farm sites in Passamaquoddy Bay.

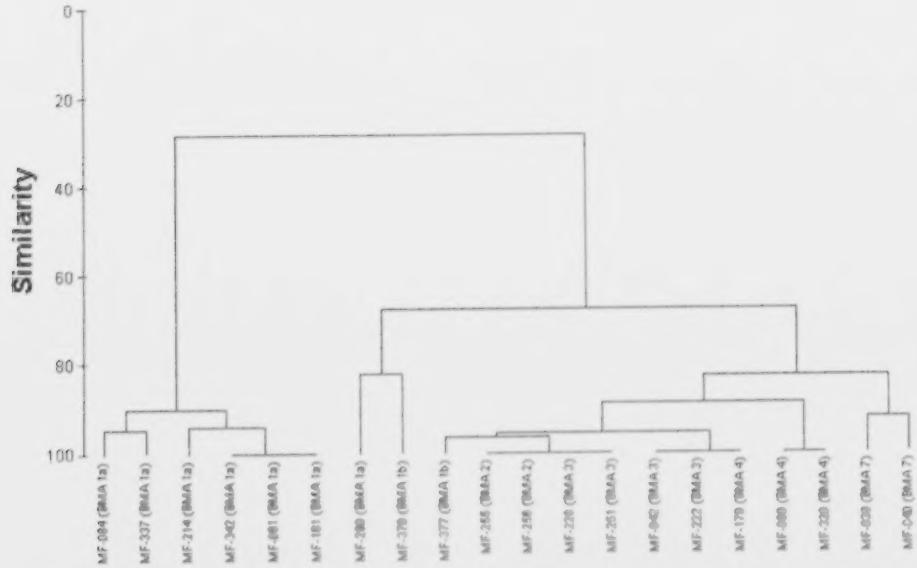


Fig. 12. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps among 5-km radius buffer zones of finfish farms in Passamaquoddy Bay.

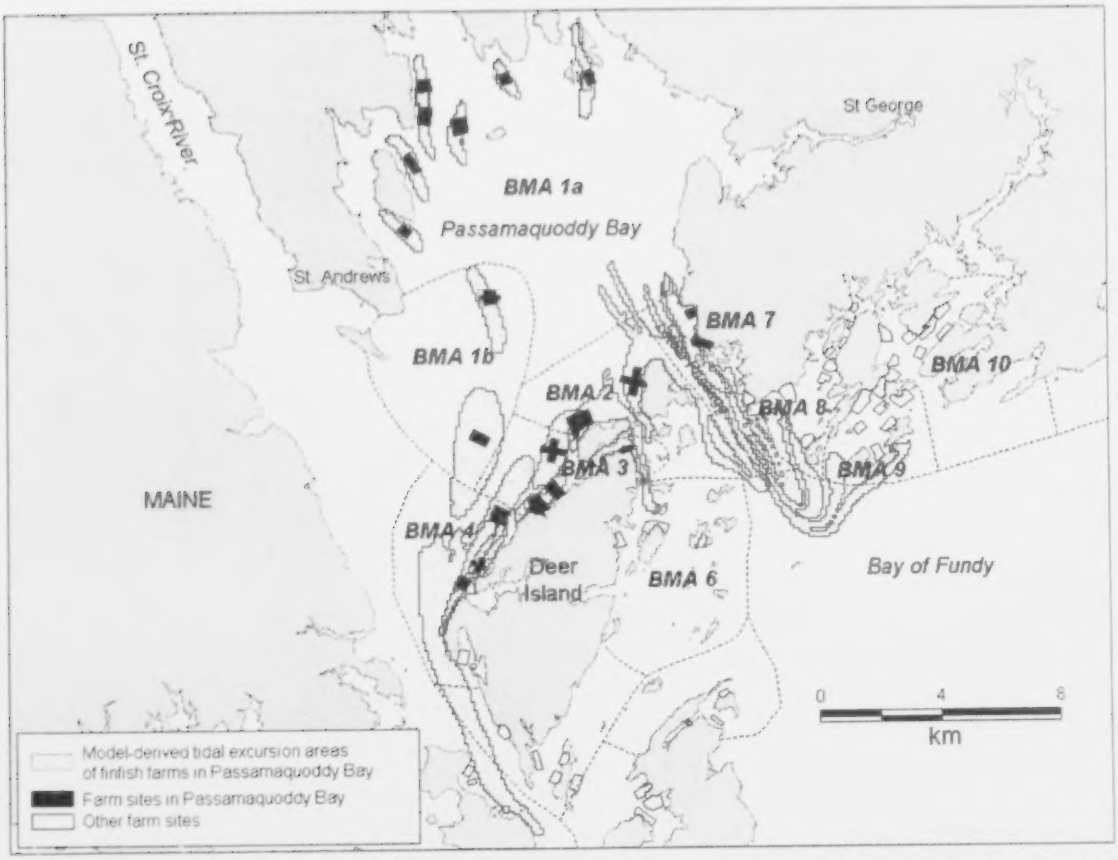


Fig. 13. Map showing model-derived tidal excursion areas of all finfish farms in Passamaquoddy Bay.

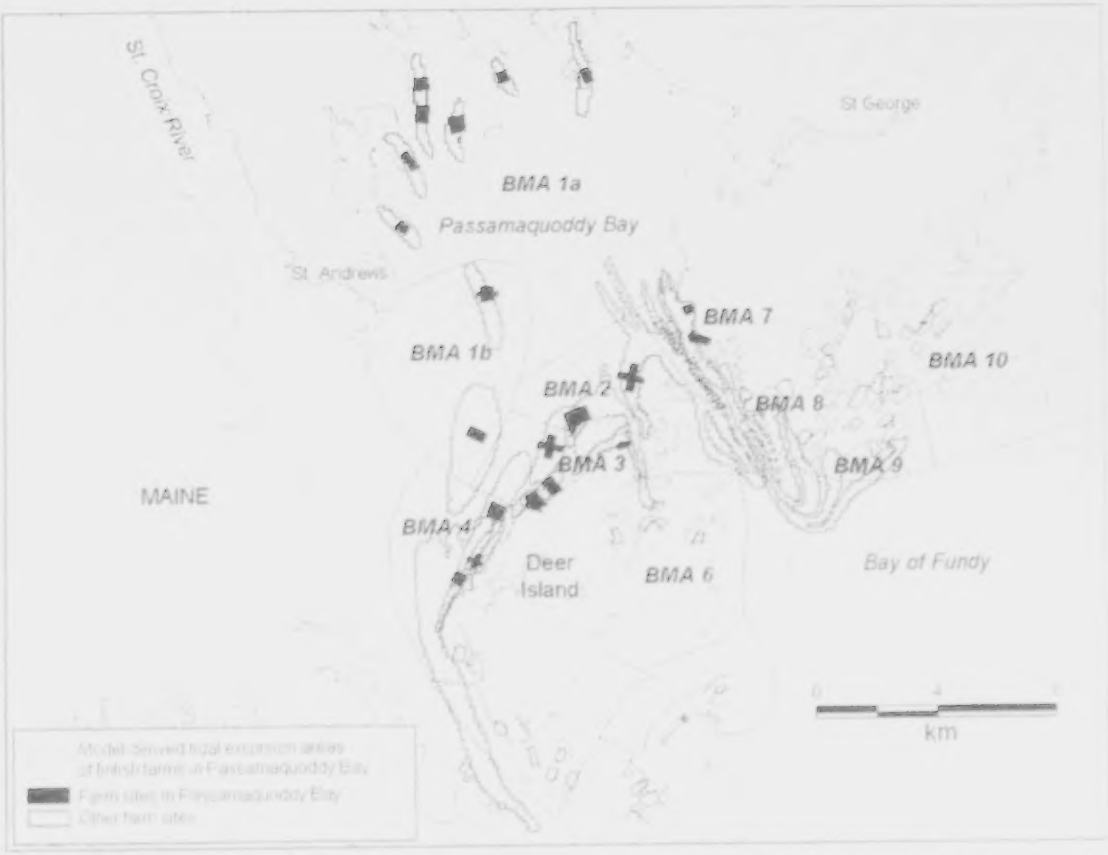


Fig. 13. Map showing model-derived tidal excursion areas of all finfish farms in Passamaquoddy Bay.

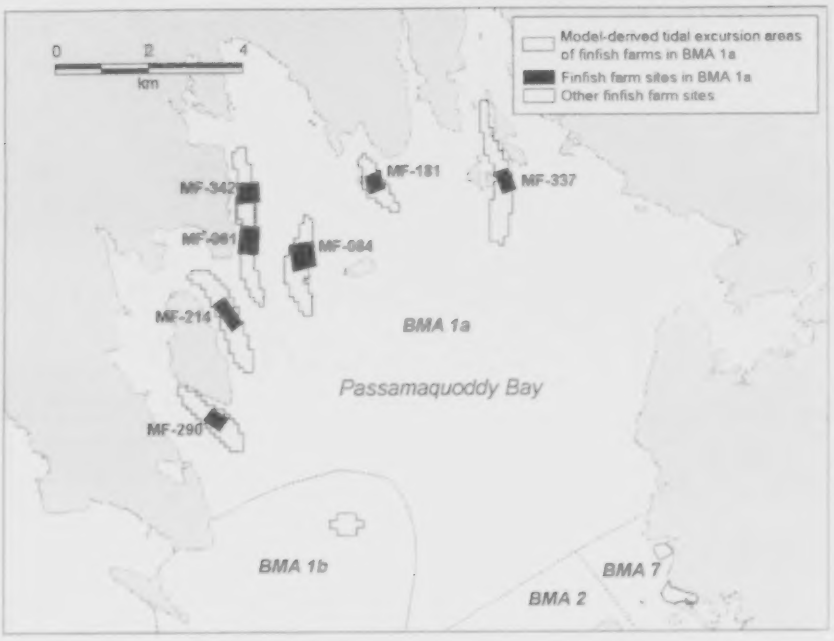


Fig. 14. Model-derived tidal excursion areas of finfish farms in BMA 1a, northern Passamaquoddy Bay.

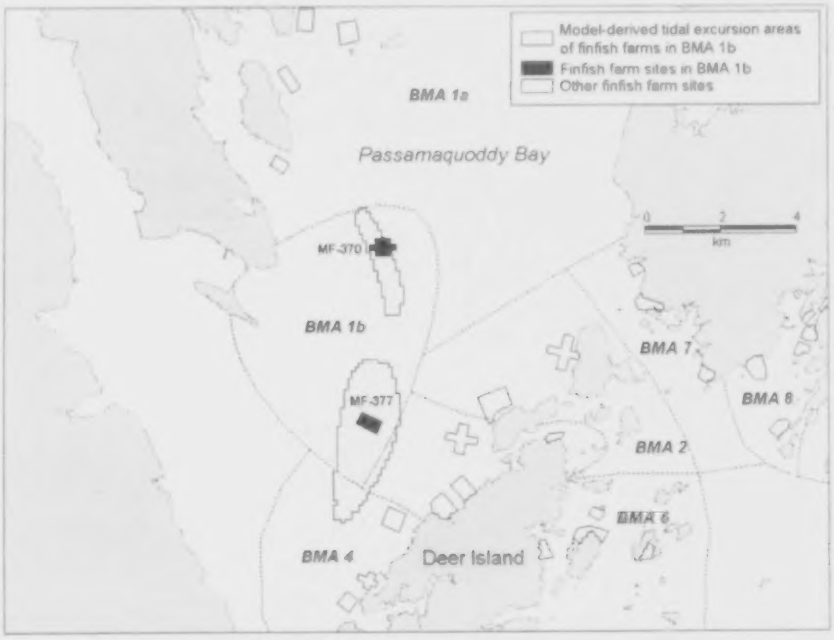


Fig. 15. Model-derived tidal excursion areas of finfish farms in BMA 1b, central Passamaquoddy Bay.

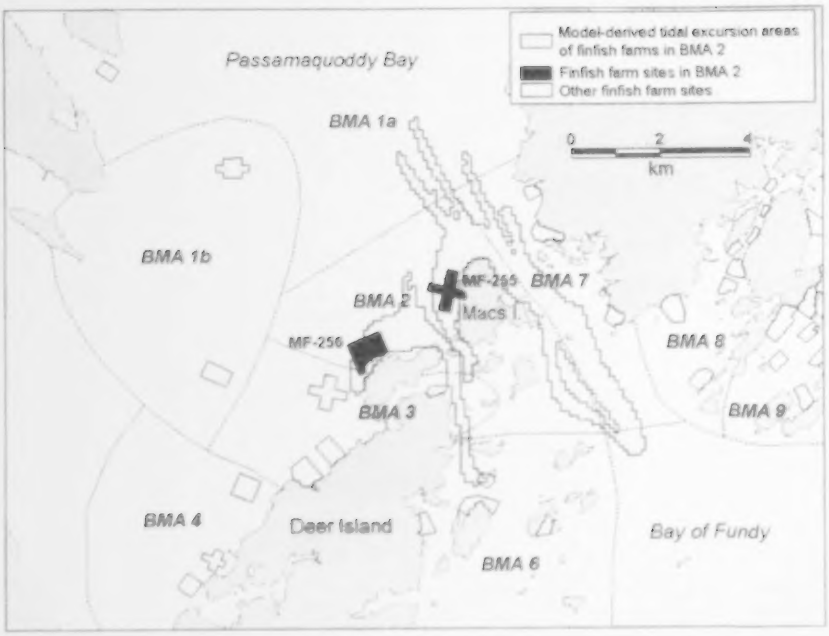


Fig. 16. Model-derived tidal excursion areas of finfish farms in BMA 2, Macs Island area.

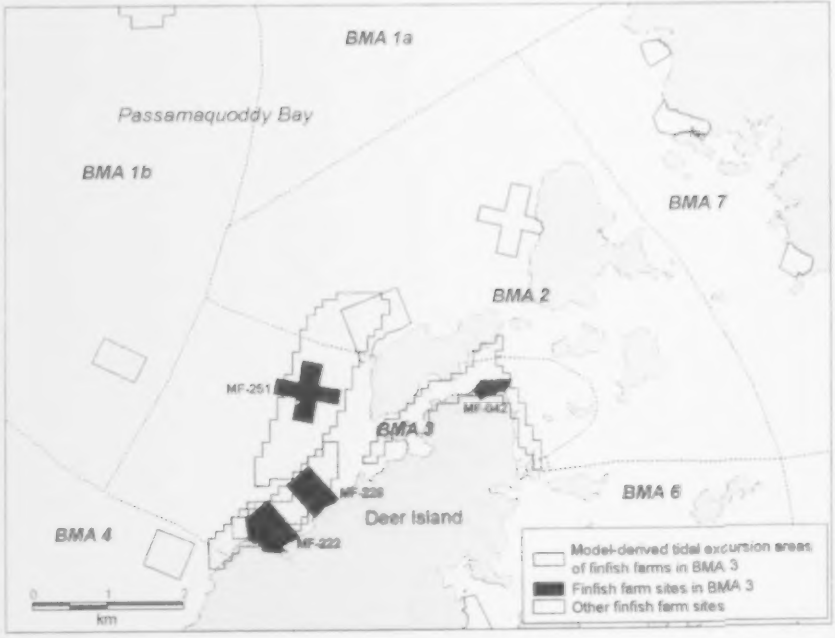


Fig. 17. Model-derived tidal excursion areas of finfish farms in BMA 3, northern Deer Island area.

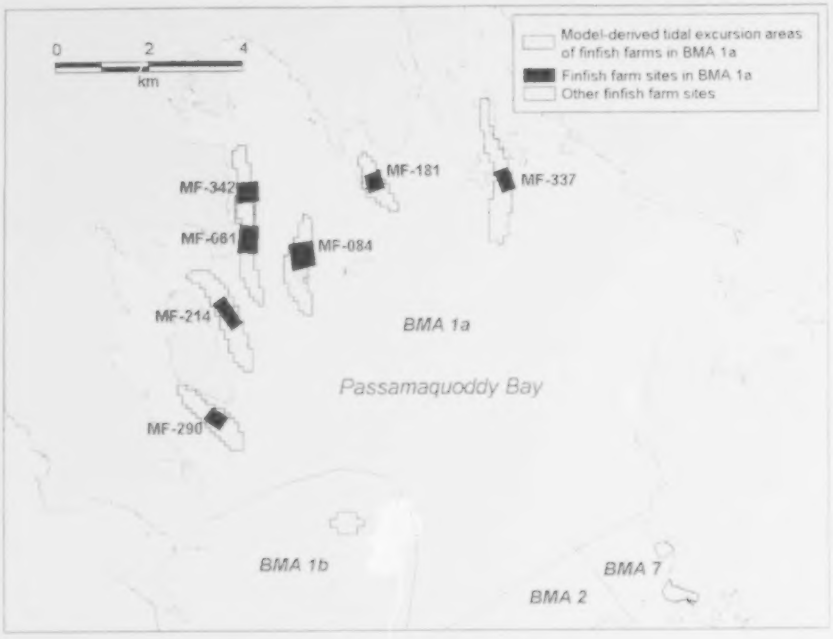


Fig. 14. Model-derived tidal excursion areas of finfish farms in BMA 1a, northern Passamaquoddy Bay.

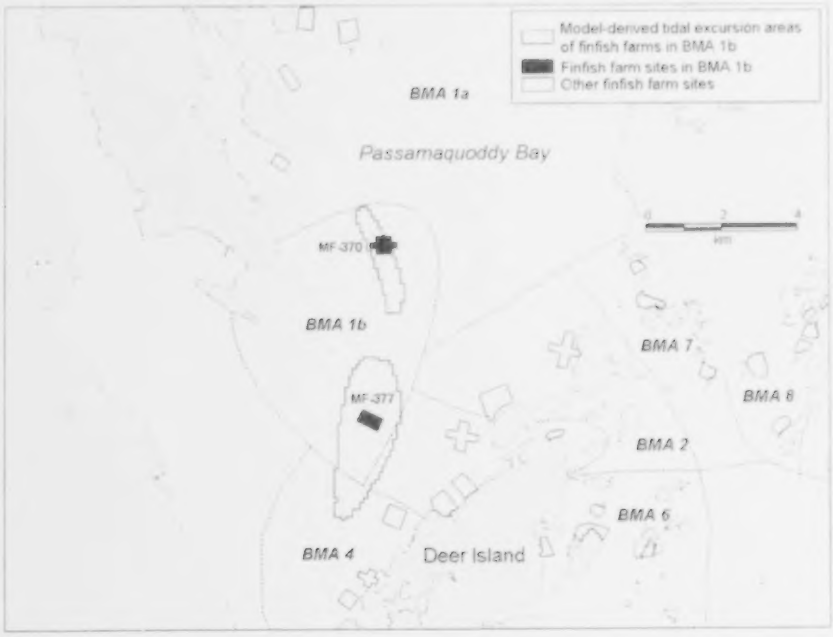


Fig. 15. Model-derived tidal excursion areas of finfish farms in BMA 1b, central Passamaquoddy Bay.

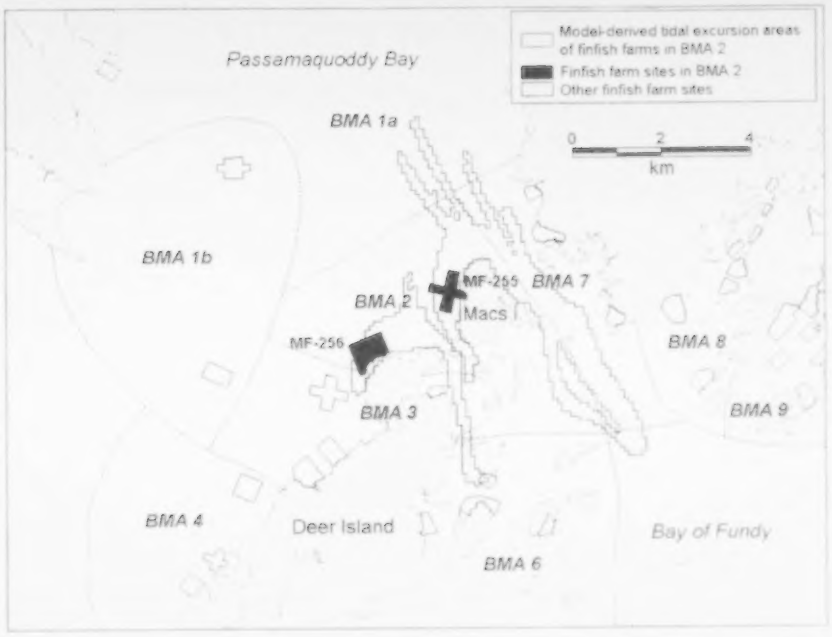


Fig. 16. Model-derived tidal excursion areas of finfish farms in BMA 2, Macs Island area.

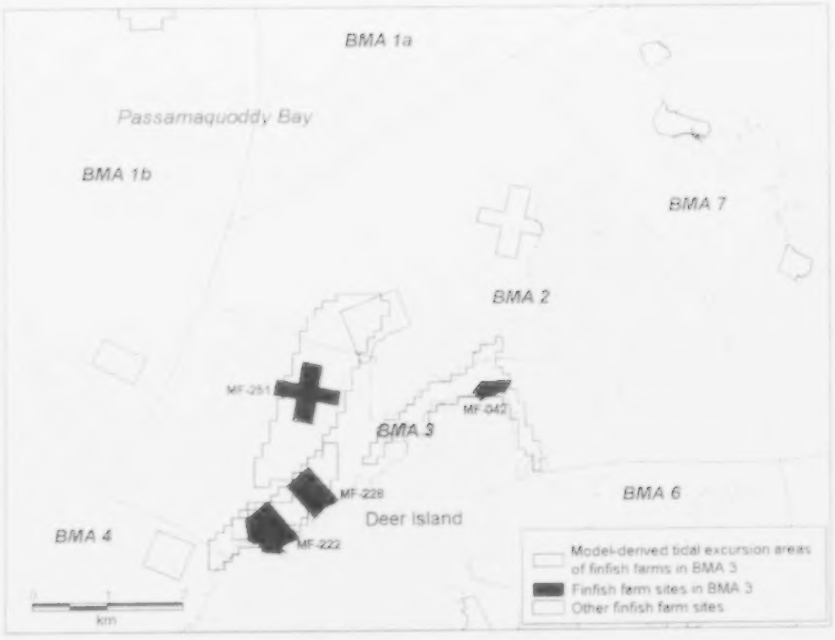


Fig. 17. Model-derived tidal excursion areas of finfish farms in BMA 3, northern Deer Island area.

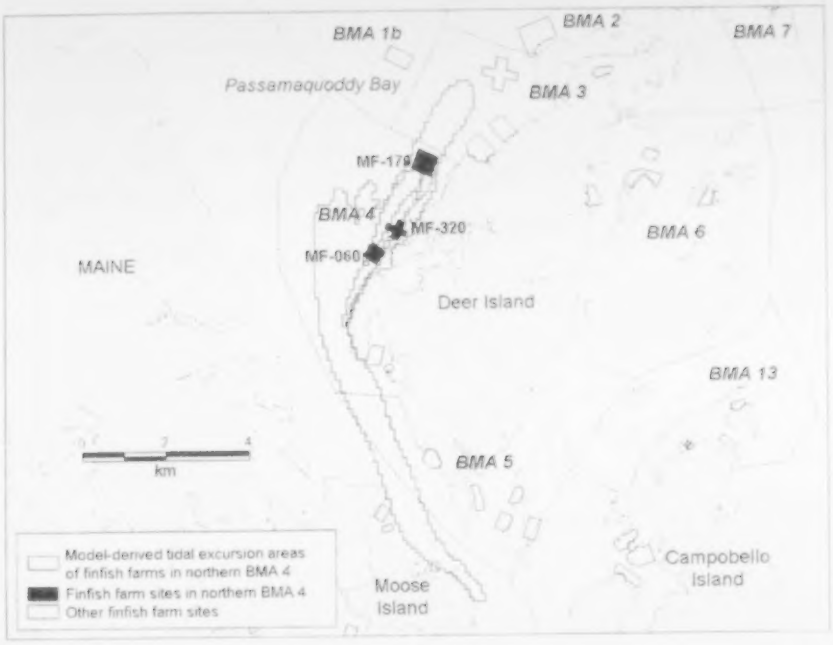


Fig. 18. Model-derived tidal excursion areas of finfish farms in the northern part of BMA 4. western Deer Island area.

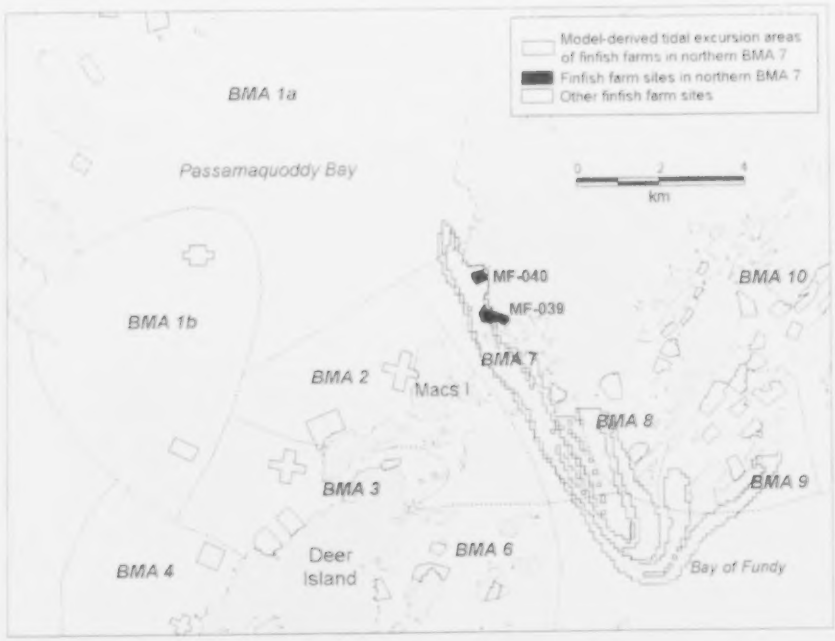


Fig. 19. Model-derived tidal excursion areas of finfish farms in the northern part of BMA 7. Letete Passage.

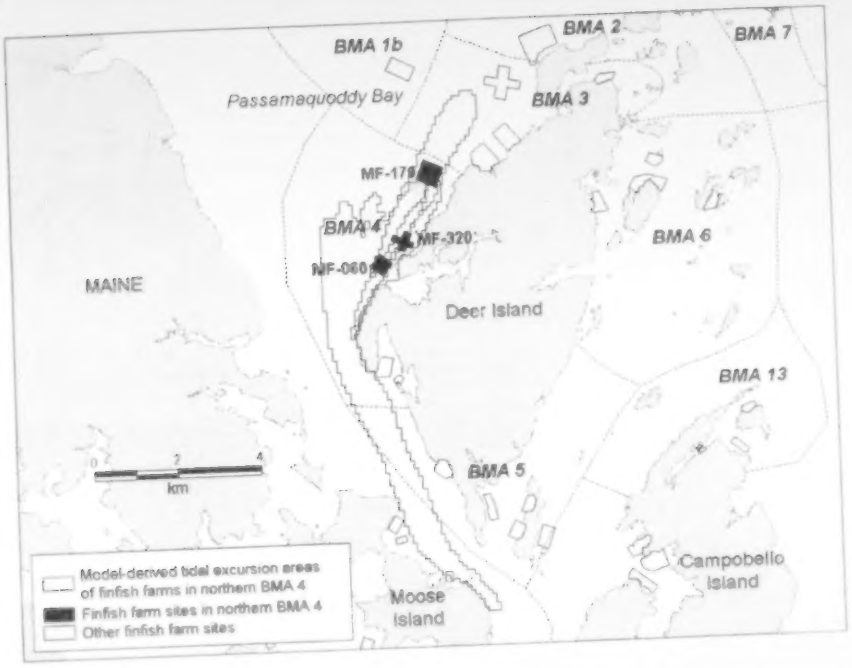


Fig. 18. Model-derived tidal excursion areas of finfish farms in the northern part of BMA 4, western Deer Island area.

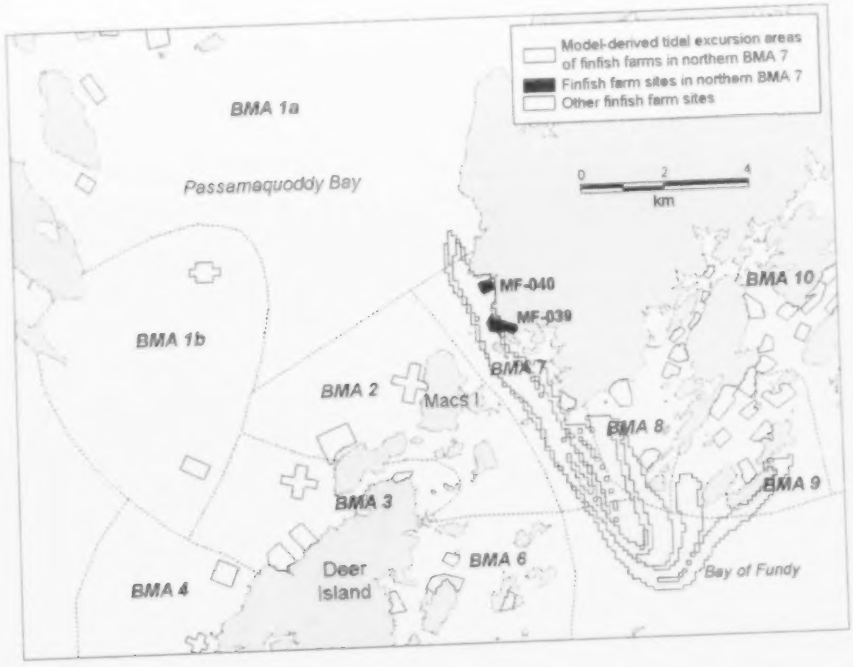


Fig. 19. Model-derived tidal excursion areas of finfish farms in the northern part of BMA 7, Letete Passage.

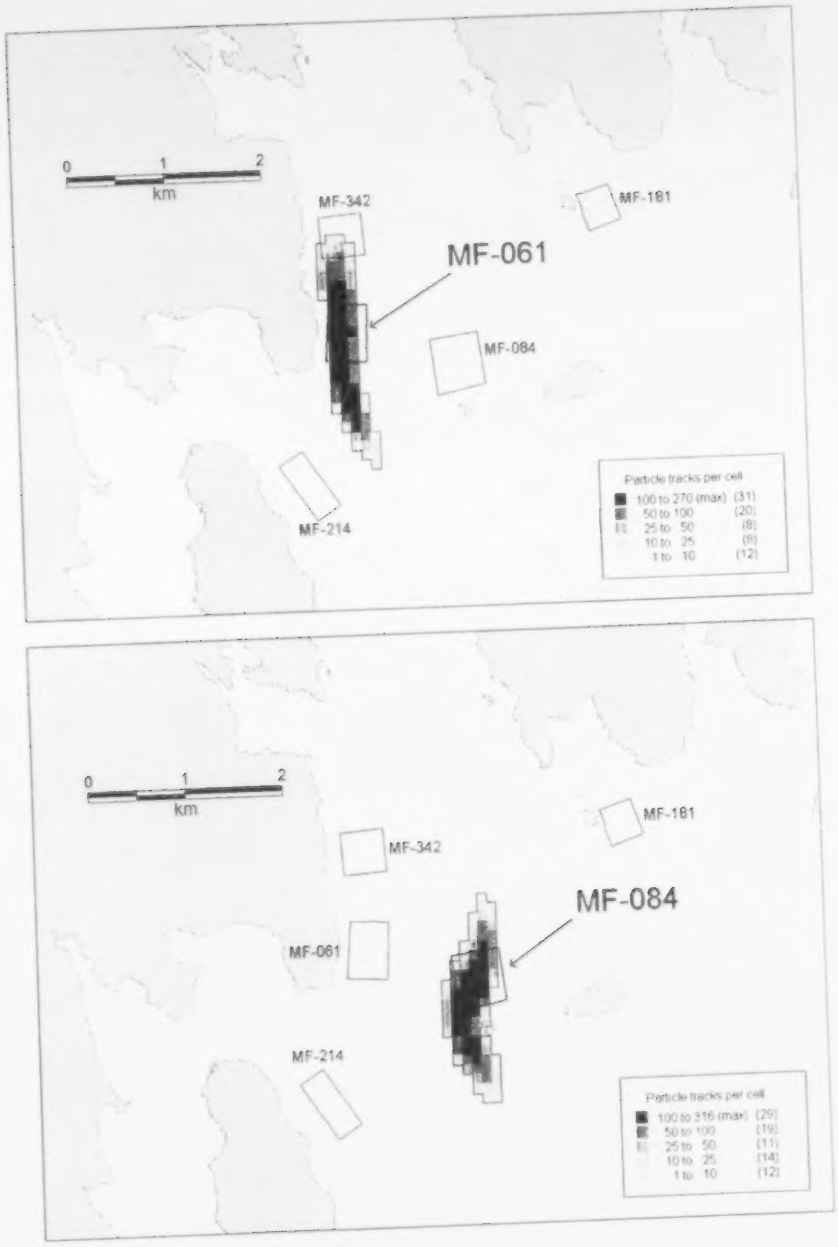


Fig. 20. Model-derived tidal excursion areas of each finfish farm in BMA 1a, northern Passamaquoddy Bay. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm at hourly intervals over a 12-h period (see text for details). Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

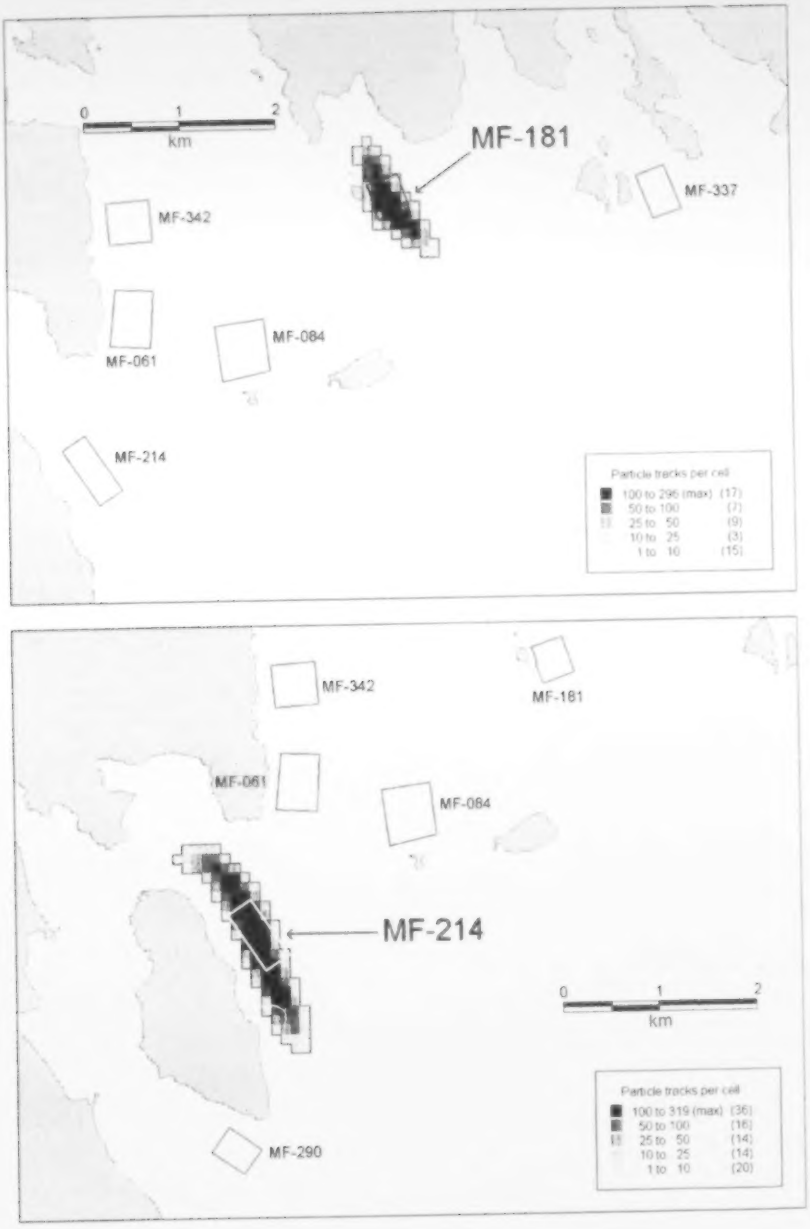


Fig. 20 continued.

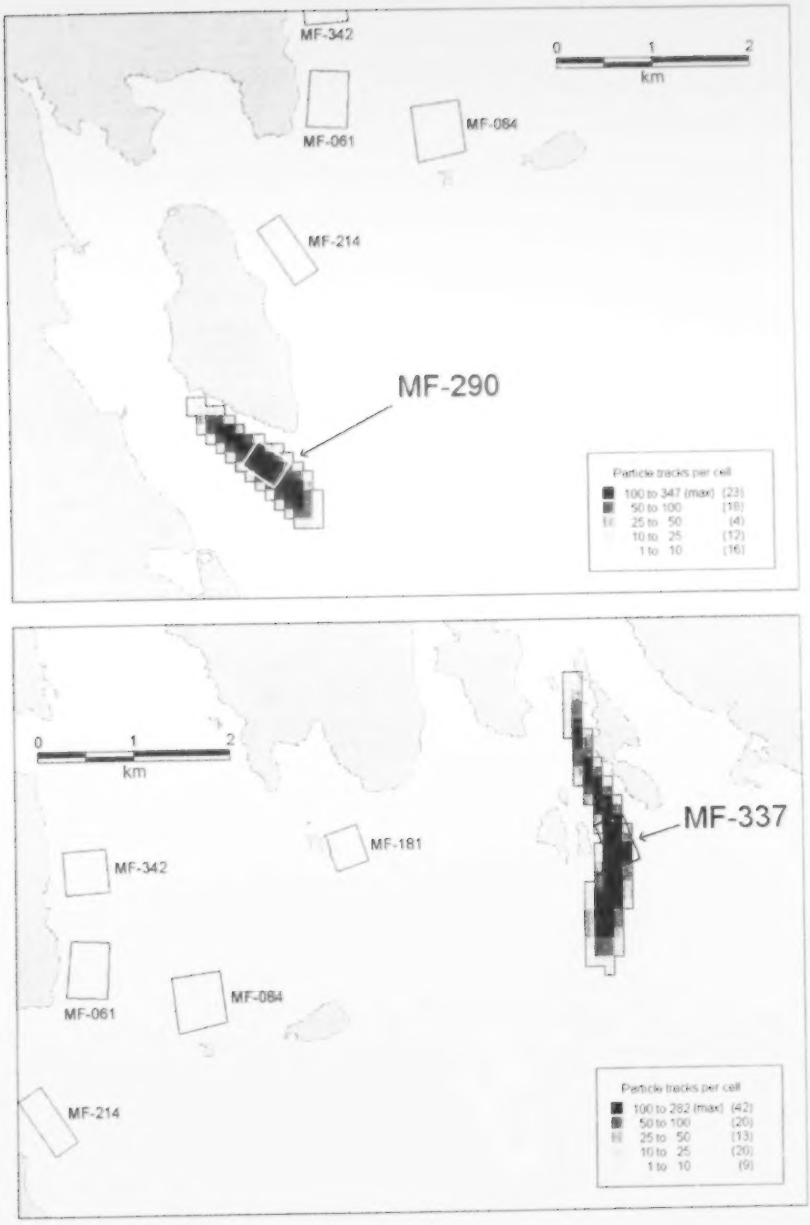


Fig. 20 continued.

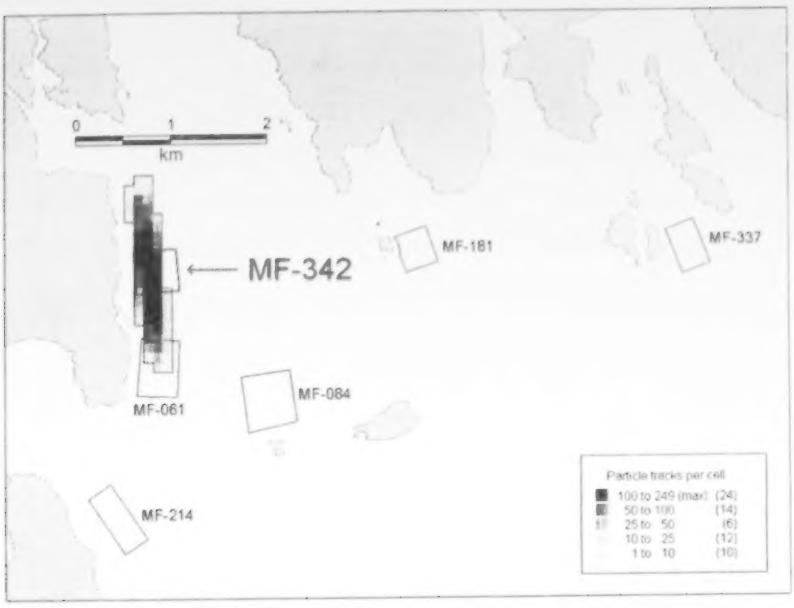


Fig. 20 concluded.

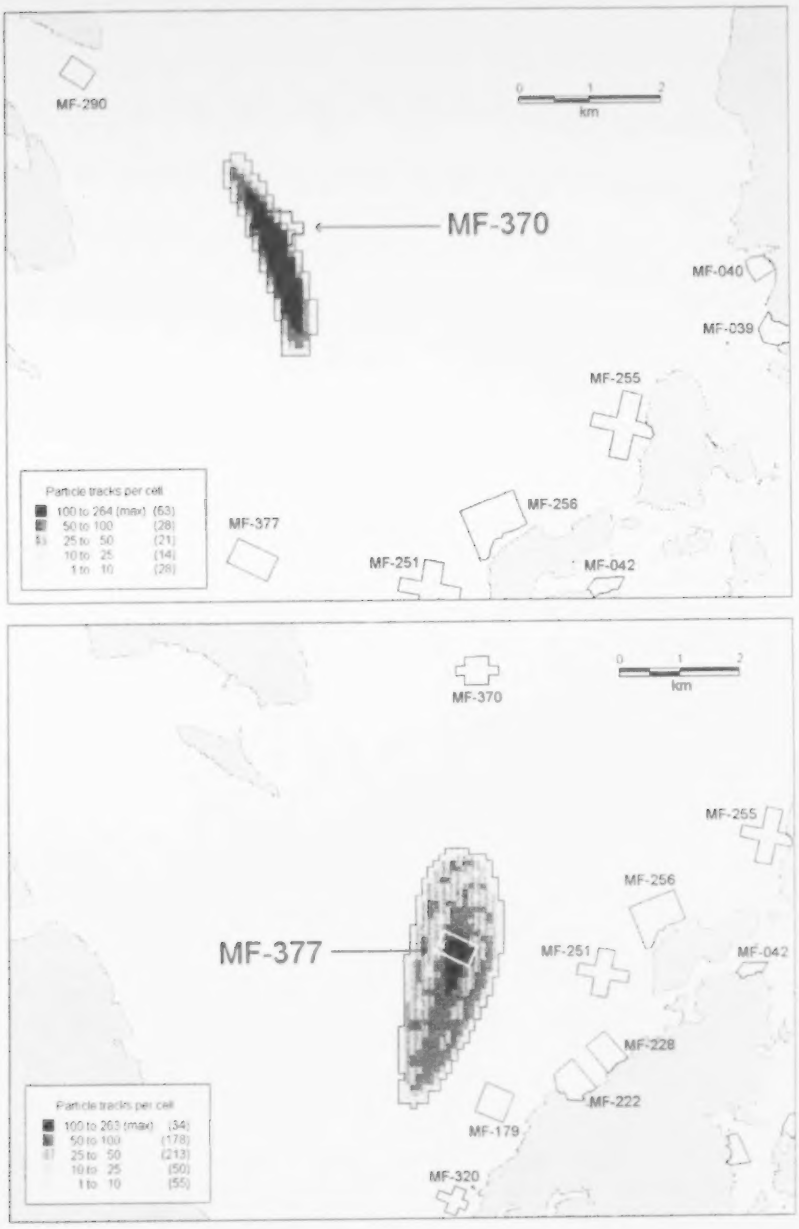


Fig. 21. Model-derived tidal excursion areas of each finfish farm in BMA 1b, central Passsamaquoddy Bay. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm (slightly fewer in some cases) at hourly intervals over a 12-h period (see text for details). Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

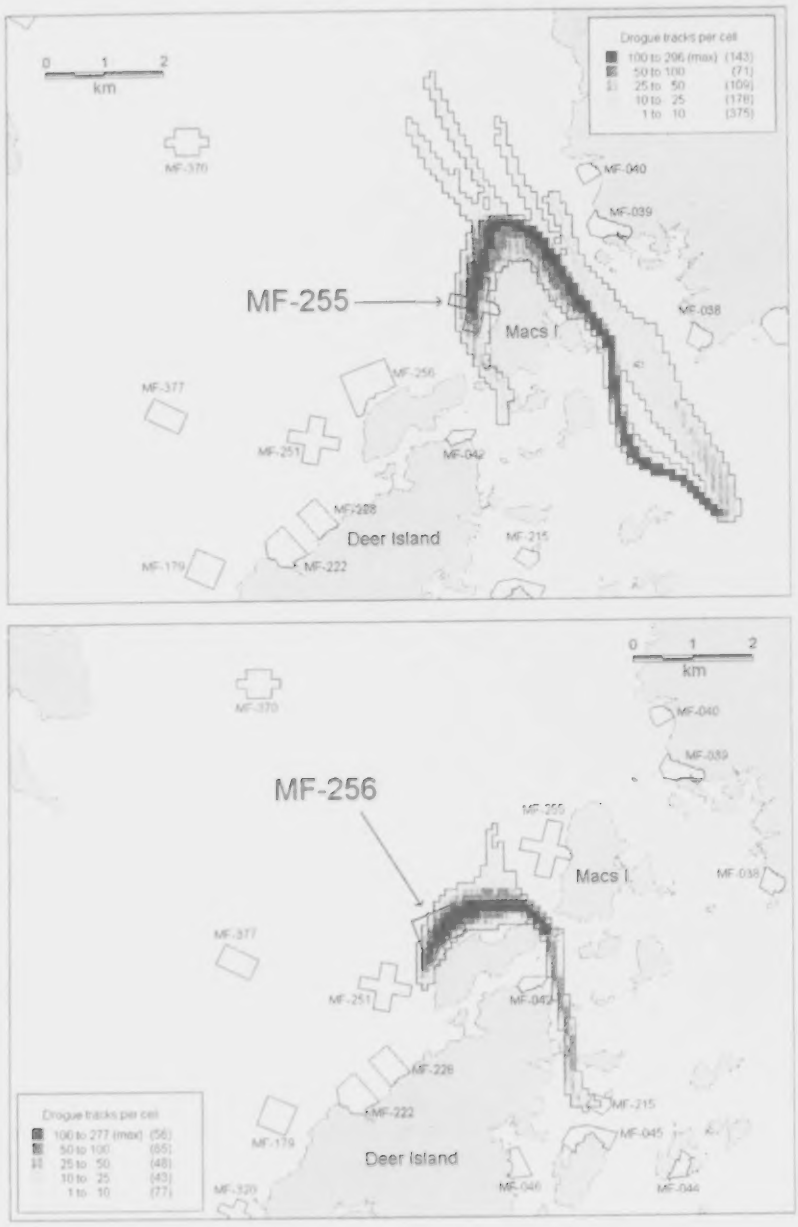


Fig. 22. Model-derived tidal excursion areas of each finfish farm in BMA 2, Macs Island area. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm at hourly intervals over a 12-h period (see text for details). Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

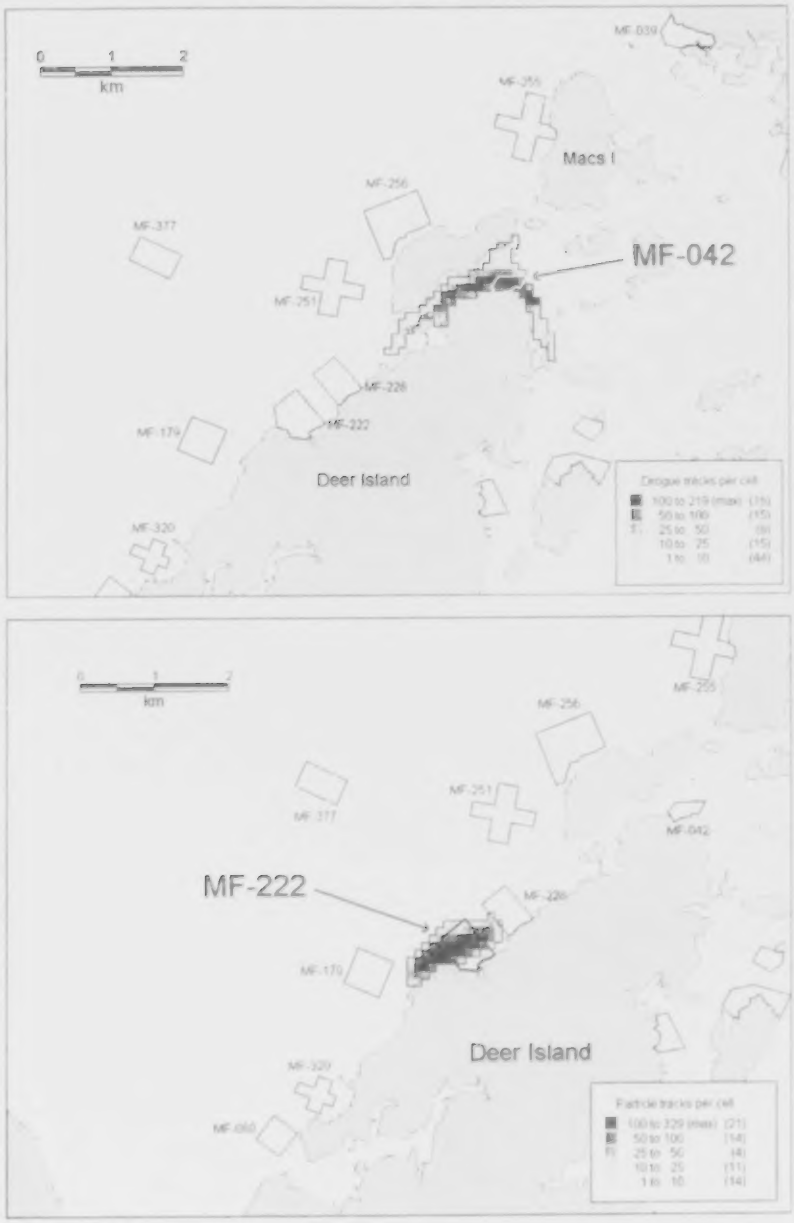


Fig. 23. Model-derived tidal excursion areas of each finfish farm in BMA 3, western Deer Island area. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm (slightly fewer in some cases) at hourly intervals over a 12-h period (see text for details). Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

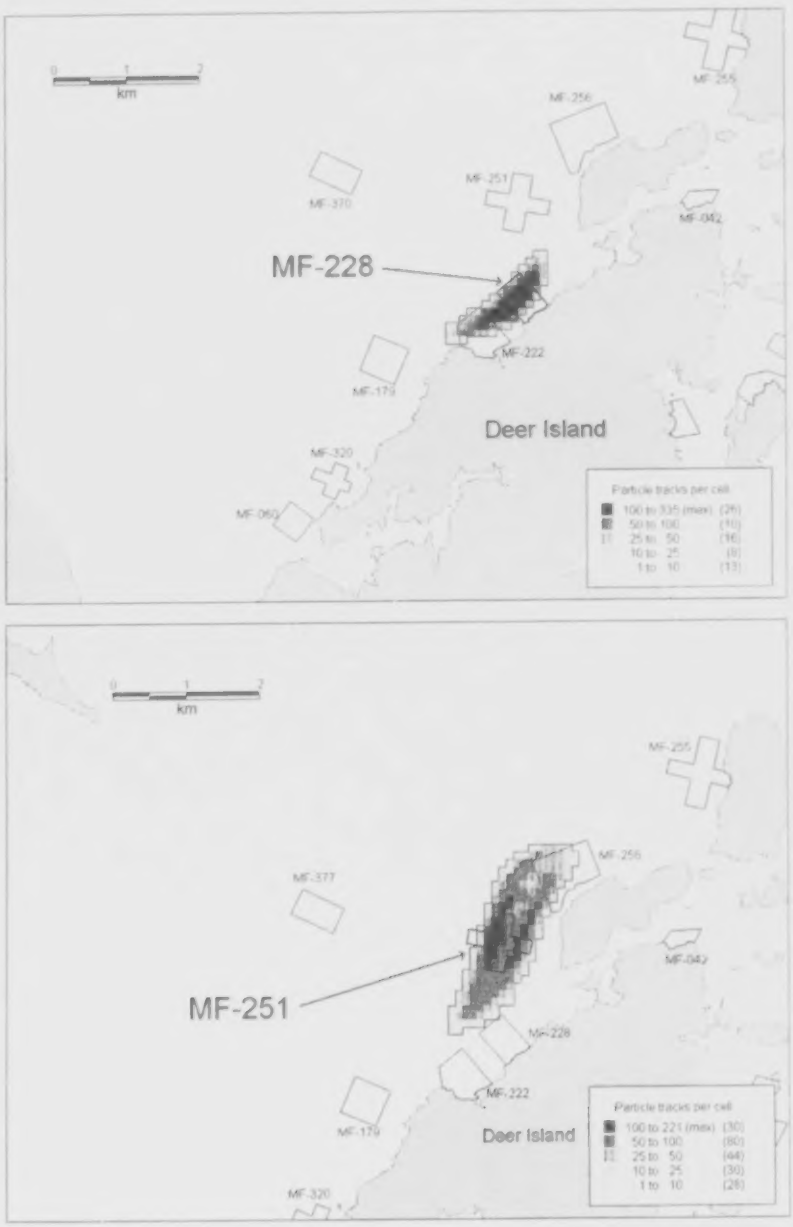


Fig. 23 concluded.

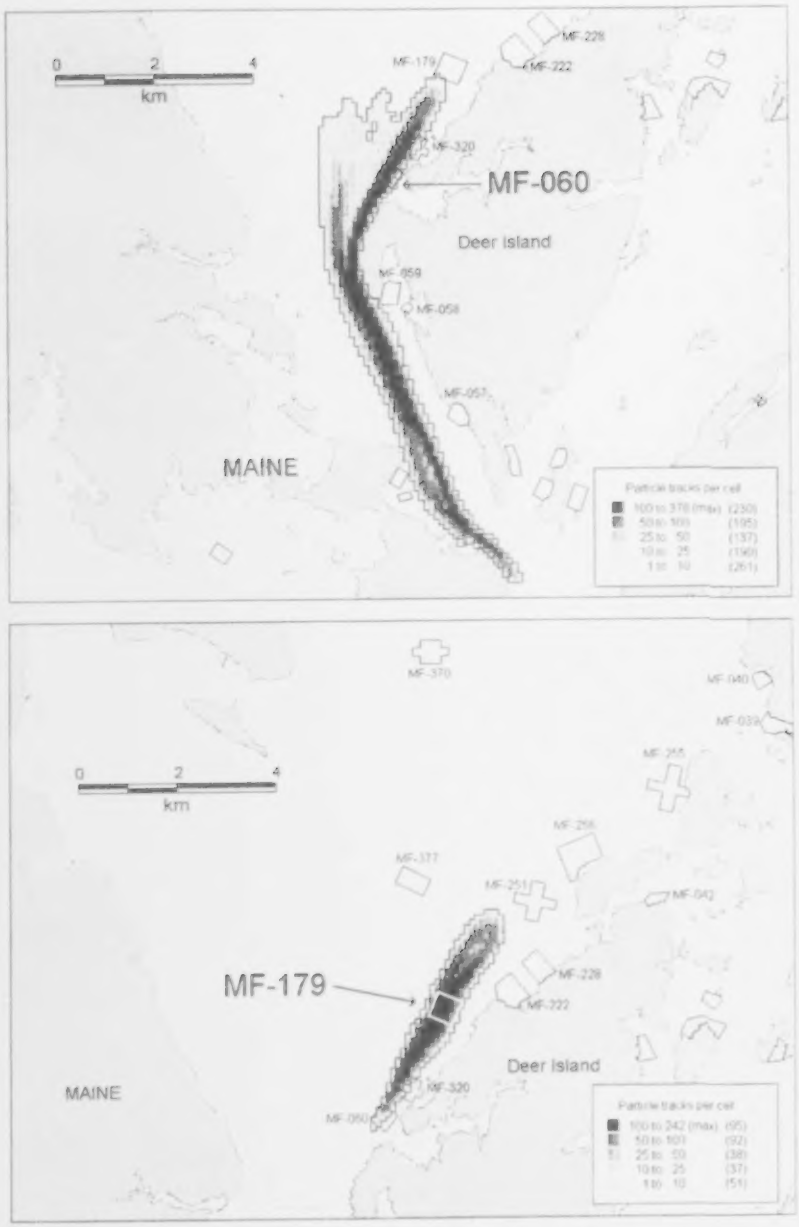


Fig. 24. Model-derived tidal excursion areas of each finfish farm in the northern part of BMA 4, western Deer Island area. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm (slightly fewer in some cases) at intervals over a 12-h period (see text for details). Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

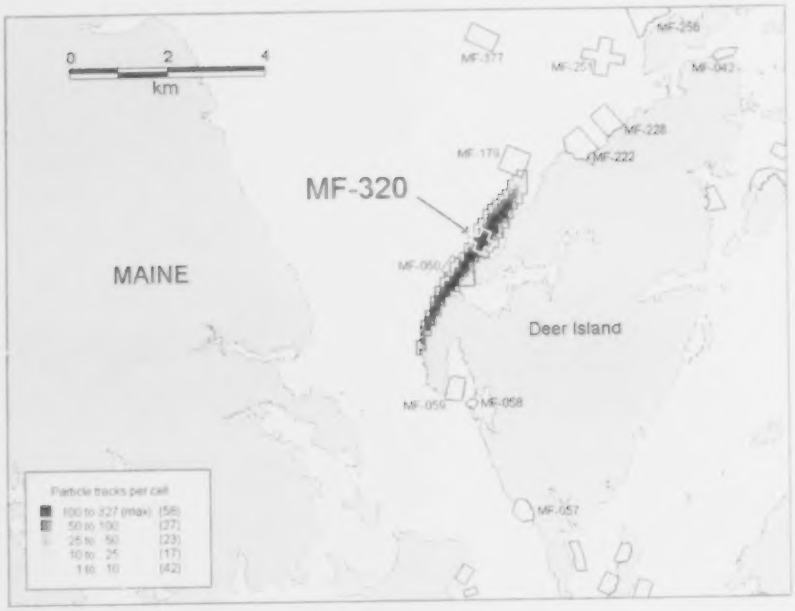


Fig. 24 concluded.

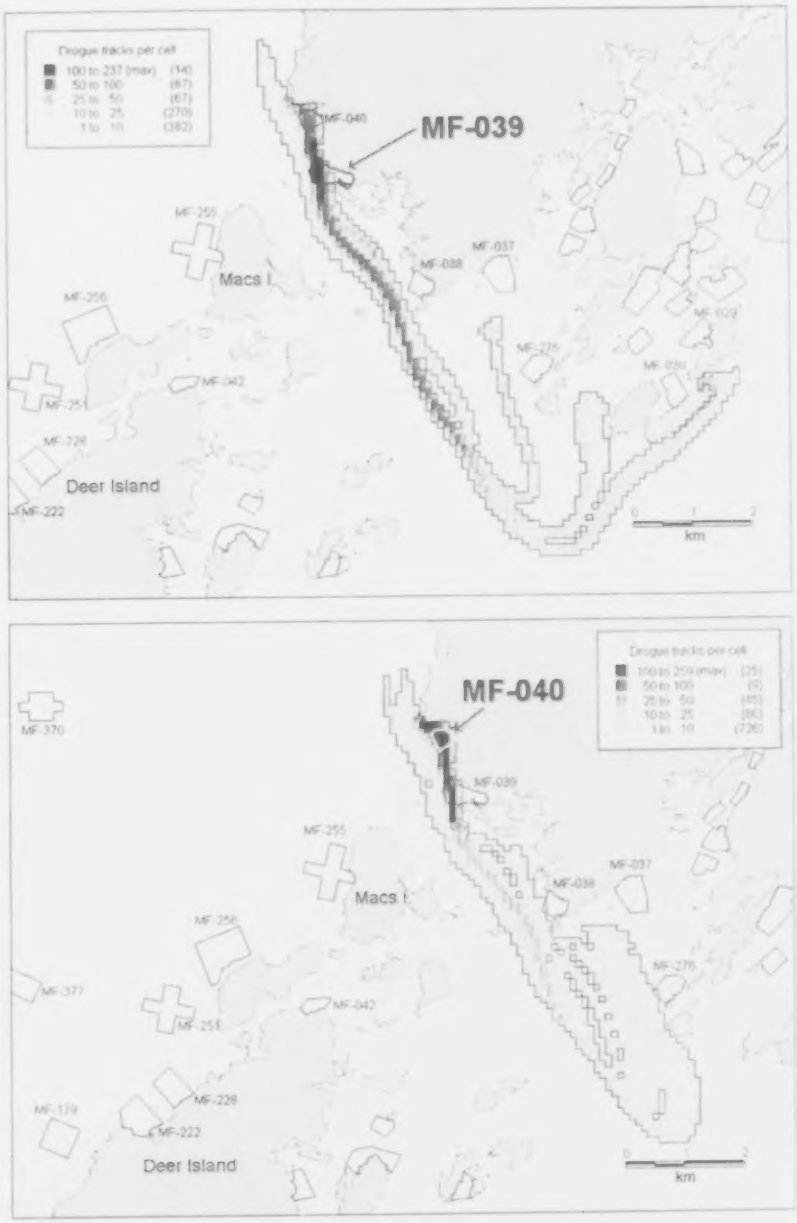


Fig. 25. Model-derived tidal excursion areas of each finfish farm in the northern part of BMA 7, Letete Passage. The shading represents the number of model-derived particle tracks intersecting each 100 × 100 m square cell. Thirty-six particles were released from each farm (slightly fewer in some cases) at hourly intervals over a 12-h period (see text for details). Each particle was tracked for one tidal excursion (12.42 h) or until it stopped upon hitting the shore, whichever came first. Farm sites are shown as small polygons. Numbers in parentheses in the legend are the numbers of cells within each range of particle track counts.

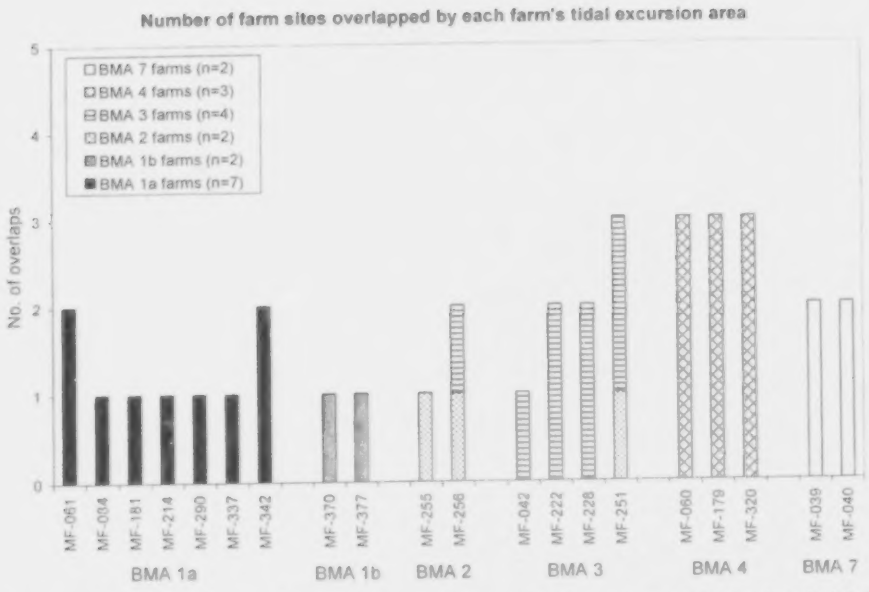


Fig. 26. Number of finfish farm sites overlapped by each farm's model-derived tidal excursion area in Passamaquoddy Bay. The x-axis lists the farms from which the tidal excursion areas originated. The numbers include overlaps with the originating farm.

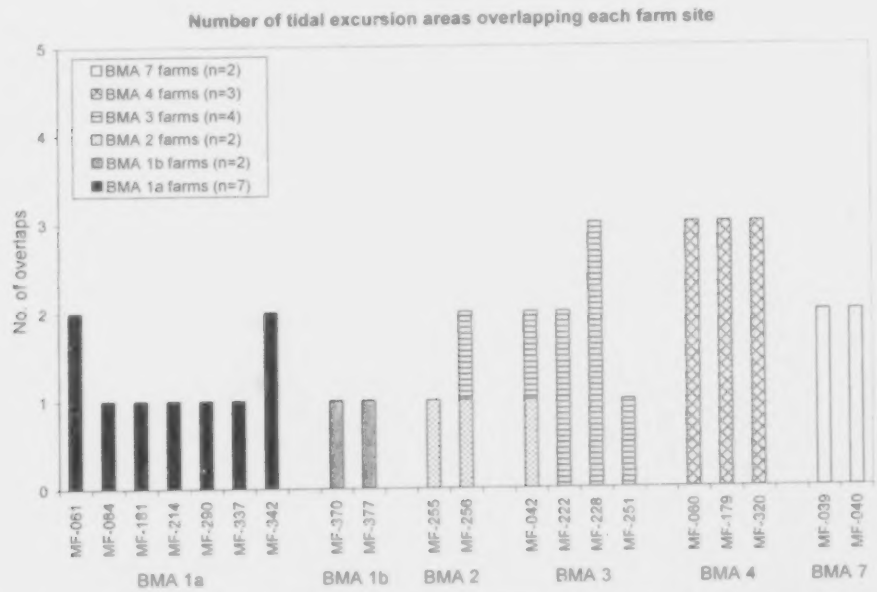


Fig. 27. Number of model-derived tidal excursion areas overlapping each finfish farm site in Passamaquoddy Bay. The x-axis lists the receiving farms. The numbers include overlaps with the originating farm.

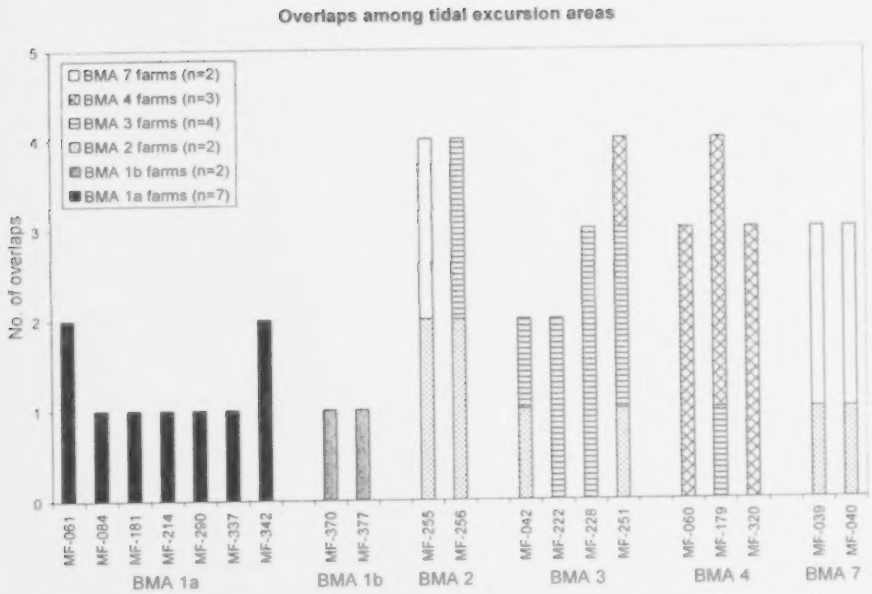
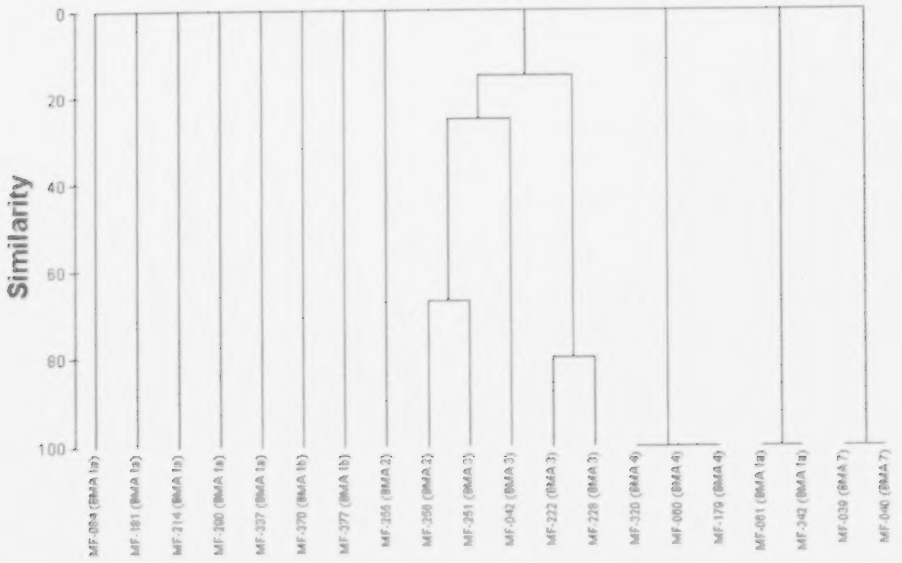
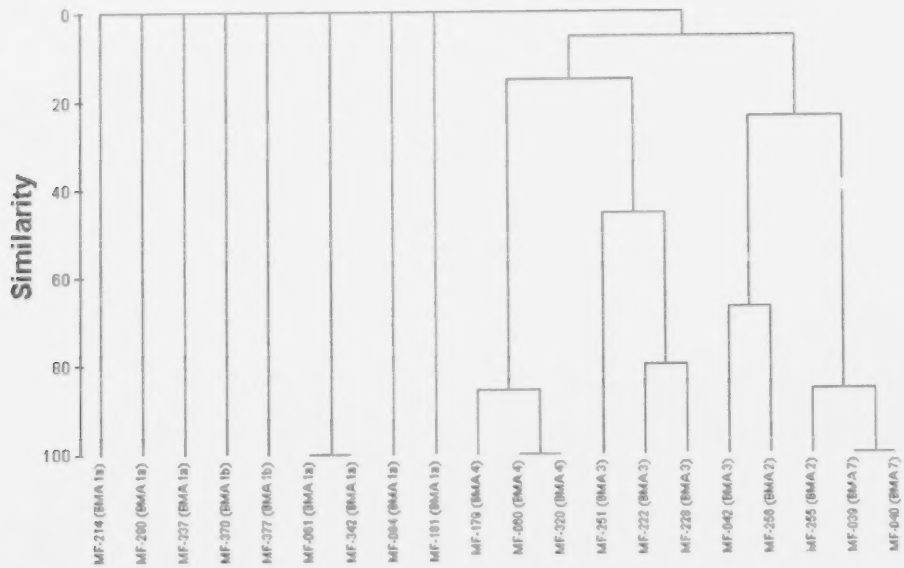


Fig. 28. Number of overlaps among model-derived tidal excursion areas of finfish farms in Passamaquoddy Bay. The numbers include overlaps with the originating farm.

Fig, 29. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps of each farm's model-derived tidal excursion area with farm sites in Passamaquoddy Bay. The x-axis lists the farms from which the tidal excursion areas originated.



Fig, 30. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps of model-derived tidal excursion areas with farm sites in Passamaquoddy Bay. The x-axis lists the receiving farms.



Fig, 31. Cluster analysis using Bray-Curtis similarity coefficients calculated on the presence or absence of overlaps among model-derived tidal excursion areas of finfish farms in Passamaquoddy Bay.

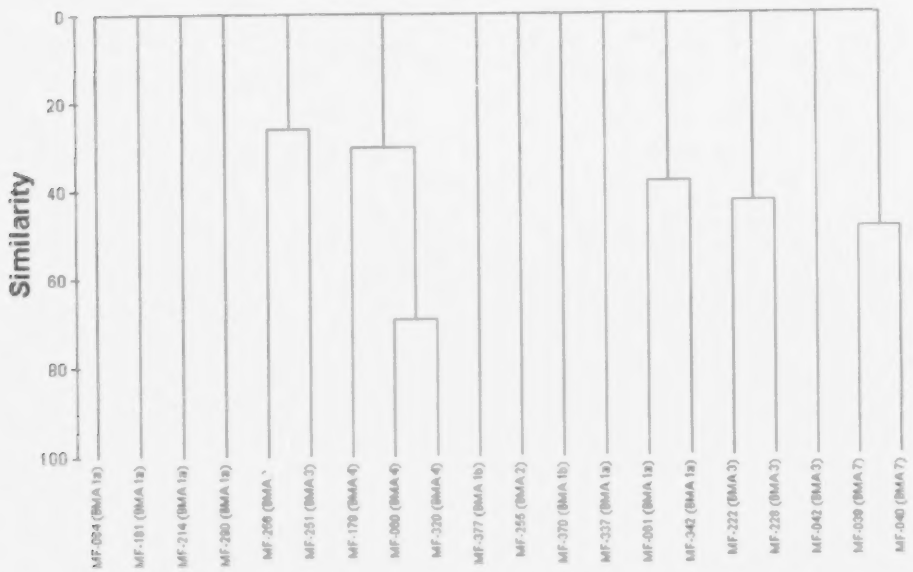


Fig. 32. Cluster analysis using Bray-Curtis similarity coefficients calculated on the number of model-derived particle tracks from each finfish farm which overlapped farm sites in Passamaquoddy Bay. The x-axis lists the farms from which the particle tracks originated.

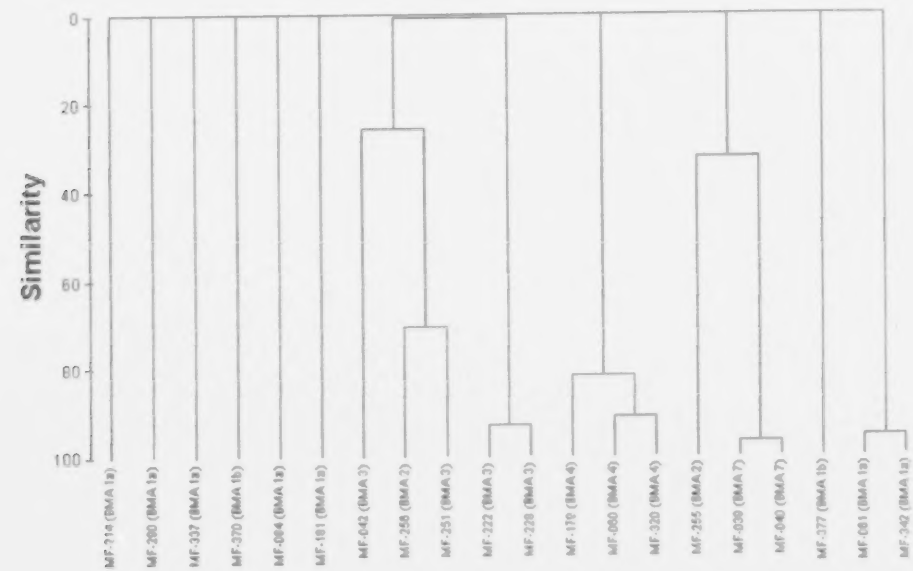


Fig. 33. Cluster analysis using Bray-Curtis similarity coefficients calculated on the number of model-derived particle tracks from each finfish farm which overlapped tidal excursion areas of farms in Passamaquoddy Bay. The x-axis lists the farms from which the particle tracks originated.

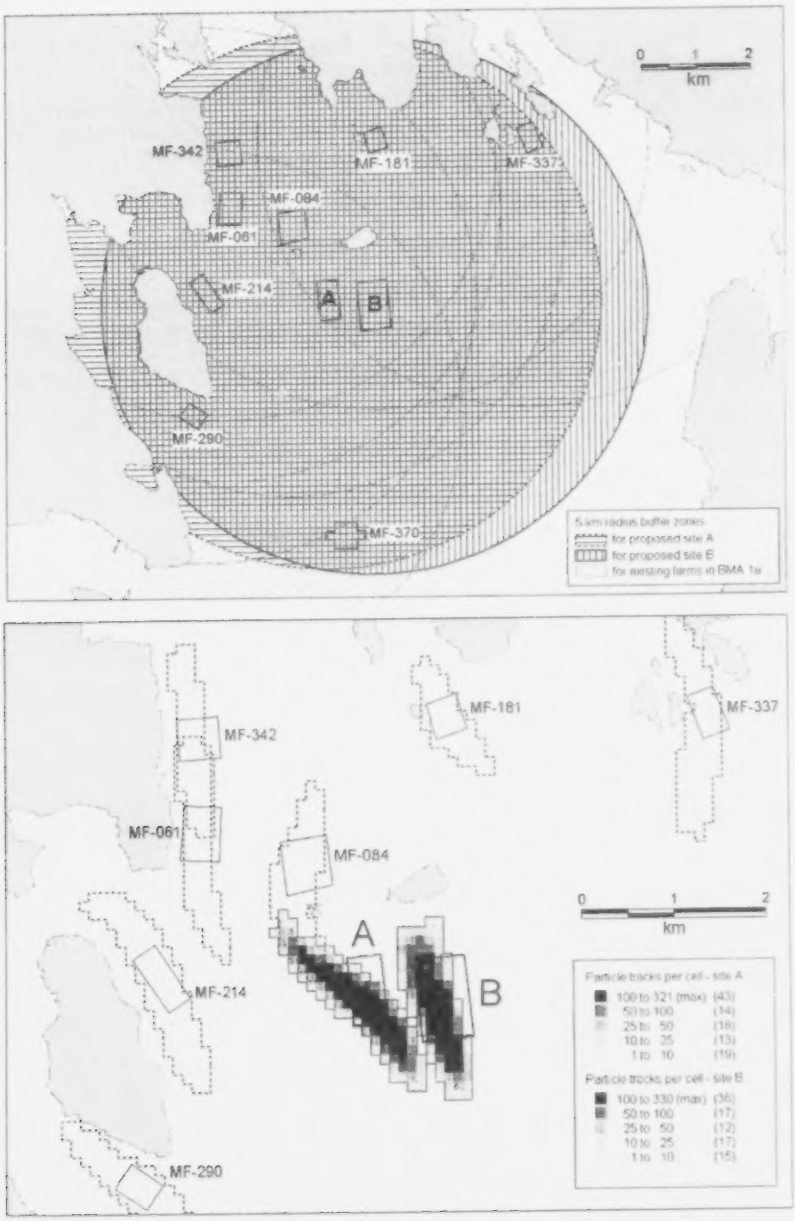


Fig. 34. Water exchange areas for two options (A and B) for a new salmon farm in northern Passamaquoddy Bay (BMA 1a). Top: 5-km radius buffer zones. Bottom: model-derived tidal excursion areas (refer to the caption for Fig. 20 for details); the dotted lines show the outlines for the model-derived tidal excursion areas of existing farms (see also Fig. 20).